Investigating implicit learning in relation to clinical and sub-clinical autistic traits: Evidence of intact learning in the social domain

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Copyright statement

Abstract

Implicit learning processes enable us to acquire language skills and social knowledge without conscious awareness or an intention to learn. Because Autism Spectrum Disorder (ASD) is partly characterised by social communication impairments, it has been suggested that a reduced capacity for implicit learning may underlie these deficits. The majority of studies on this topic have provided little support for this suggestion. However, a handful of studies did demonstrate a link between autistic traits and reduced non-conscious learning, particularly when the learning included a social component. The experiments presented in this thesis were designed to further investigate the hypothesised relationship between autistic traits and implicit learning.

An initial study investigated implicit statistical learning in young lower-functioning autistic children, a group largely overlooked by previous research. This school-based research was, however, interrupted at a critical stage by COVID-19-related school closures in the UK. Research then re-focussed on implicit social learning in adults, and how it relates to dimensional autistic traits. Based on methods developed by Hudson et al. (2012) and Macinska (2019), the four remaining studies in this thesis utilised a social learning phase in which pro- and anti-social characters conveyed their dispositions to participants via dynamic combinations of gaze directions and facial expressions. Unlike the aforementioned studies, no evidence was found that autistic traits (or ASD diagnoses) related to a reduced ability to learn social information implicitly. Instead, when participants were required to attend closely to the characters' eyes (an important source of 'mental state' information in the learning-phase stimuli), higher autistic traits were associated with superior social learning from the undetected facial cues. Evidence from this thesis therefore suggests that implicit learning remains intact in those with elevated autistic traits. However, attentional factors, including the autism-related propensity to divert attention from others' eyes, may moderate implicit learning from social cues.

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Over the course of this PhD, I married Rachel and welcomed our daughter Nefeli into the world. While wedding planning and midnight baby care were not especially conducive to clear, focussed, analytical thinking, they did at least provide a useful distraction from any PhD-related stress. I hope that this PhD makes you both proud and acts as a reminder that you can achieve anything.

Contents

Chapter 1. Introduction

1.1. Setting the scene

From the moment we are born, most people demonstrate a natural ability to absorb knowledge about the structure and regularities in their environment. For example, when infants are brought up in a language-rich home, they seem to learn their first words effortlessly, without any need for formal instruction. As they grow older, most children then ‘pick up’ the grammatical rules of their native language, again seemingly without effort or tuition. Similarly, people learn ‘naturally’ how much personal space to give others, or how to tailor their behaviour to different social situations, without being schooled in the complexities of social etiquette. Implicit learning is thought to be central to these remarkable feats. Learning is considered ‘implicit’ when it occurs without any intention to learn and results in skills or knowledge of which the learner has little conscious awareness. Social communication and language skills are thought to develop predominantly through implicit, non-intentional learning mechanisms, as are motor skills (Lieberman, 2000).

Autism Spectrum Disorder (ASD) is a lifelong condition characterised by persistent deficits in social communication and social interaction (American Psychiatric Association, 2013). Language impairments (Boucher, 2003) and motor deficits (Belmonte, 2022; Bo et al., 2016) are also commonly observed in people with autism. Because these skills are acquired primarily through implicit learning, it has been suggested that a reduced capacity for non-intentional learning might play an important role in ASD. There is evidence both for and against this proposal, as will be discussed later in this chapter. However, enough evidence exists to make it a worthwhile area for further investigation and the central topic of this thesis. Indeed, this thesis initially investigates a particular sub-category of implicit learning (implicit statistical learning) which may be particularly relevant to social communication skill development in both typically developing (TD) and autistic populations.

1.1.1. Structure of this thesis

The global COVID-19 outbreak (2020-2021) caused significant disruption during this programme of research. Ongoing barriers to the testing of school-age participants necessitated a reformulation of research questions part way through the programme. As such, this thesis is somewhat unusual in structure containing, as it does, two introductions.

Introduction and Study 1: This first (pre-COVID) introductory chapter serves as a general introduction to key concepts, with a greater emphasis on implicit statistical learning (ISL) in autistic children (the subject of Study 1). The first introduction discusses ISL in greater detail before examining the evidence for and against ISL's possible influence on autistic symptomatology. A re-examination of the evidence prompts suggestions that current research findings may be open to alternative interpretations. The first introduction ends by discussing a rival (or perhaps complementary) theory that also accounts for the reduced social communication skills common in autism. The Social Motivation Theory suggests that atypical allocation of attention may cause autistic children to miss critical social input that would otherwise facilitate implicit learning. Study 1 (which investigates ISL in young, lower-functioning autistic children) is then presented in Chapter 2.

Introduction II and studies 2, 3, 4 and 5: After Study 1 (which was interrupted part way through data collection by COVID restrictions), the reader will find a second introductory chapter. 'Introduction II' explains the rationale for a series of re-formulated studies that initially required neither child participants nor in-person data collection. The chapter first discusses the utility of investigating implicit learning in relation to dimensional autistic traits in the general population. It then introduces several strands of evidence that suggest that implicit learning difficulties associated with autistic traits might lie specifically within the social domain. The studies that follow the second introduction were designed with two key objectives in mind. Their primary goal was to investigate whether increased autistic traits (or clinical ASD diagnoses – see Study 5) were associated with reduced implicit learning from subtle social cues. An important secondary goal was to investigate the potential mechanism behind any autism-related implicit learning differences found.

General discussion and conclusions: The final chapter provides a closing discussion of all five studies. Chapter 8 summarises the studies and their contributions to academic knowledge. Findings from this thesis are combined with other researchers' findings to draw conclusions about implicit learning and its relationship to clinical and sub-clinical autistic traits. Broader methodological limitations are also discussed alongside recommendations for future research.

Throughout this thesis, identity-first and person-first language are used in roughly equal measure. This choice was made to acknowledge and respect the different views held on this issue within the autism community and amongst academic professionals.

1.2. Defining implicit statistical learning

1.2.1. Implicit learning

The term 'implicit learning' was coined by Arthur Reber in the late 1960s. In his seminal study, Reber (1967) presented participants with sequences of letters and asked them to reproduce the sequences from memory. Unbeknownst to participants in the experimental group, a finite-state artificial grammar governed the order in which the letters could appear. Reber found that, as the trials progressed, the participants who were exposed to the grammar-governed sequences made fewer errors than control participants, who were presented with random letter sequences. The task was described to all participants as a simple 'memory experiment', and no reference was made to any underlying structure. The improved task performance in the experimental group was therefore attributed to non-conscious (implicit) learning of the grammatical rules underlying the sequences.

This conclusion was supported by a second study in which Reber again asked participants to memorise a series of secretly grammar-governed letter sequences. Participants were subsequently informed that the sequences followed a hidden underlying grammar and were asked to judge whether new letter sequences conformed to those rules. Half of the new sequences were constructed using the grammar, whereas half were not. Reber found that participants were able to identify grammatical and non-grammatical sequences at a level far above chance, indicating again that knowledge about the underlying structure had been acquired (Reber, A. S., 1967). Interestingly though, participants were unable to verbalise any of the rules required to make these judgements. Since Reber's study, numerous researchers have used similar methods to reproduce the finding that participants can reliably improve implicit learning task performance without developing declarative awareness of how those improvements were made (Schiff & Katan, 2014).

Several decades after Reber's initial study, researchers have still to settle upon a universally recognised definition of 'implicit learning'. However, learning is generally accepted as 'implicit' when *a)* it occurs in the absence of any intention to learn, *b)* it results in knowledge, or a skill, that is difficult to express verbally and *c)* the learner has little awareness of how that knowledge or skill was acquired (Perruchet & Pacton, 2006).

By way of contrast, *explicit* learning occurs whenever the learner makes a conscious and deliberate effort to acquire a skill, solve a problem or attain new knowledge (Hulstijn, 2005). As mentioned previously, the development of language, social communication and motor skills generally meet these 'implicit learning' criteria. A growing body of evidence provides support for this view, as will be discussed later in this chapter.

There are, of course, numerous situations in which language, social and motor skills are developed *explicitly*. After all, children are explicitly taught new vocabulary in school, frequently reminded by embarrassed parents to say 'please' and 'thank you' and regularly choose to spend time practising complex motor tasks (for example playing a musical instrument or perfecting dance moves). However, it remains the case that the majority of language, social and motor learning, especially during early development, is thought to take place via non-intentional (implicit) learning mechanisms (Aslin et al., 1998; Conway et al., 2010; Meltzoff et al., 2009).

1.2.2. Implicit <u>statistical</u> learning (ISL)

While the majority of learning in these three domains may be implicit, there is an important distinction between language and social learning and the development of motor skills. It is well established that motor skills can be developed without conscious awareness (Masters et al., 2019). For example, it would seem clear that an infant learning to walk does not do so by learning explicit rules about arm and leg movements. Even when a child makes a conscious attempt to walk, development of the balance and coordination required is likely to take place at a level below explicit awareness. In the laboratory, researchers have often used the pursuit rotor task (Eysenck & Thompson, 1966), or its modern-day equivalents, to study implicit motor learning. In such tasks, participants are asked to keep a stylus centred over a small target which moves around the perimeter of a predetermined shape. As trials progress, participants typically track the target more accurately, indicating visuomotor adaptation and learning. Learning in such tasks is considered implicit because there is seemingly no explicit strategy available to participants to improve task performance.

While social communication learning and motor learning may share some underlying cognitive processes, evidence suggests that these two types of implicit learning may also operate somewhat separately. For example, Stark-Inbar and colleagues (2017) argued against a single global mechanism for implicit learning after finding a poor correlation between participants' performance on a visuomotor adaptation task (which measured implicit motor learning) and a serial reaction time task (a common method for assessing implicit sequence learning, as will be discussed later[1]). One important difference between language and social learning and the implicit development of motor skills is the extent to which the former necessarily rely on the processing of statistical regularities in the environment.

Take, for example, the process of early language acquisition. Human babies are born with no innate understanding of their native language. To even begin the process of understanding spoken language, they face a fundamental challenge: the accurate segmentation of fluent speech into words. It is worth reflecting, at this point, on what a difficult challenge this could pose to a baby. The words printed on this page are separated by neat, regular spaces and punctuation marks. Withoutthemsentencesarefarhardertoread. In natural spoken language, much like the previous 'sentence', individual words are rarely separated by neat gaps or pauses, making it seemingly problematic to determine when one word ends and another begins. This is true even for maternal infant-directed speech, where only around 9% of utterances consist of words isolated by pauses of at least 300ms (Brent & Siskind, 2001).

Saffran and colleagues (1996), in their seminal work, demonstrated that infants as young as eight months old were able to overcome this word-segmentation problem by processing implicitly the transitional probabilities between speech sounds. In their study, infants were familiarised with a continuous speech stream consisting of three-syllable nonsense words repeated in random order. Because the speech stream contained no acoustic cues or prosodic variation, the only cues to word boundaries were the transitional probabilities between syllables, which were lower between words than within words. After the familiarisation phase, which lasted just two minutes, the infants were exposed to further audible syllable strings. Some of these syllable strings were 'words' from the previous speech stream, whereas others, while still constructed from the same speech sounds, were not. The infants demonstrated a novelty preference, or dishabituation effect, listening longer to the 'nonwords' than the more familiar 'words'.

[1] For readers unfamiliar with the serial reaction time task, Nemeth et al.'s (2010) fairly typical example of such a task is described in section 1.5.2.

Saffran and colleagues thus provided the first evidence of young infants' ability to learn implicitly from the statistical properties of spoken language. Subsequent studies have shown that even newborn babies are able to detect certain statistical regularities present in speech (Gervain et al., 2008; Teinonen et al., 2009), providing strong evidence that this ability is innate.

It is this 'statistical' subcategory of implicit learning (and its potential role in autism) that is the initial focus of this thesis. It is therefore important to settle on a definition of the concept because, as is the case with 'implicit learning' generally, researchers have yet to form a consensus on terminology. Unusually, research relevant to this type of learning has been published in largely separate 'implicit learning' and 'statistical learning' literatures (Christiansen, 2019; Frost et al., 2019). This disjunction stems principally from their historically different approaches toward (rather than their genuinely opposing views about) a common learning mechanism. As such, this thesis will adopt Christiansen's (2019) suggestion that these previously divided literatures are reconciled under an 'implicit statistical learning' banner. As such, ISL is defined here in its broadest terms as the cognitive process that facilitates the extraction of regularities in the environment over time, without conscious awareness or an intention to learn (Christiansen, 2019; Perruchet & Pacton, 2006; Perruchet, 2018; Schapiro & Turk-Browne, 2015). For now-obvious reasons, learning that conforms to the above description has variously been referred to as both *implicit learning* and *statistical learning* in articles published previously.

1.2.3. Individual differences in ISL

A key area of interest in this thesis is whether autistic individuals have reduced ISL abilities and whether these differences (if detected) are predictive of language and social impairments. A prerequisite, therefore, is that stable ISL differences exist between individuals. While this may seem obvious, this very notion is at odds with Reber's original beliefs about the nature of implicit learning.

ISL was initially conceptualised as a fundamental, innate human ability which was cognitively and neurologically distinct from explicit learning. As such, it was hypothesised that implicit learning would possess several key characteristics (Reber, A. S. et al., 1991; Reber, A. S., 1993):

1. Independence from explicit learning and general intelligence
2. Robustness to disease and injury
3. Age independence
4. Little variability across individuals

The balance of evidence appears to support characteristics 1 and 2. From a neurological point of view, ISL has been shown to operate quite separately from explicit learning (Poldrack & Foerde, 2008). While explicit learning ability and intelligence are highly correlated, neither predicts an individual's performance on ISL measures (Gebauer & Mackintosh, 2007; McGeorge et al., 1997). Similarly, for ISL tasks that use stimuli devoid of real-world meaning (for example unfamiliar abstract symbols and artificial/nonsense 'languages'), participants' prior knowledge (for example, vocabulary) is not thought to influence task performance (Ziori et al., 2014). ISL is also often spared in conditions that affect IQ and explicit learning. For example, Atwell et al. (2003), showed that participants with intellectual disabilities performed below the level of TD controls on an explicit learning task, but showed no differences in performance on an ISL task. Similar dissociations between ISL and explicit learning have been observed in patients with Alzheimer's disease (Reber, P. J. et al., 2003), amnesia (Meulemans & Van der Linden, 2003) and Parkinson's disease (Smith & McDowall, 2006).

Recent research indicates, however, that ISL, while functional from birth (Gervain et al., 2008; Teinonen et al., 2009), does develop over time. While ISL is far less dependent on age than explicit learning, it is now known to mature throughout childhood. Finn et al. (2016) found that children achieved adult-equivalent performance on some ISL measures (but not explicit learning measures) by the age of 10. Demonstrating a similar developmental timescale, Janacsek and colleagues (2012) showed that children's implicit sequence learning ability improved until around the age of 12, after which it was found to decline. Age-related improvements have also been demonstrated in the concurrent implicit learning of adjacent and nonadjacent dependencies (Iao et al., 2021), which are discussed further in the following section.

ISL also diminishes less with aging than does explicit learning (Drag & Bieliauskas, 2010), though evidence suggests it does deteriorate somewhat in those aged over 65 (Lukács & Kemény, 2015). Importantly, recent evidence also disputes the assumption that ISL varies little between individuals. Kalra and colleagues (2019) performed a reliability study using several well-established tasks to assess ISL in young TD adults. Testing participants twice, one week apart, they discovered that serial reaction time, probabilistic classification and category learning tasks could detect stable individual differences in ISL ability. Furthermore, the study confirmed that these individual differences in ISL were not correlated with measures of explicit learning, intelligence or working memory. These findings indicate that ISL (at least in the TD population) varies reliably between individuals (Kalra et al., 2019).

1.3. Language development and ISL

Over the past two decades, it has become clear that ISL plays an important role in multiple domains of cognition, from motor planning and event processing to reading and face recognition (Frost et al., 2019). Yet no area of research in this field has received more attention than ISL's proposed link to language acquisition. As such, significant advances have been made in our understanding of how ISL contributes to language development in both typical and atypical populations.

In the case of early language acquisition, ISL is known to enable typically developing infants, as described earlier, to detect statistical regularities (Gervain et al., 2008; Teinonen et al., 2009) and to define word boundaries in speech (Saffran et al., 1996). Infants younger than 18 months have also been shown to learn (and then later identify) phonotactic regularities that are not present in their native language following short auditory presentations (Chambers et al., 2003). In 4 to 6-year-old children, ISL has been linked directly with the acquisition of syntax (Kidd, 2012). In Kidd's study, children were primed by the experimenter to describe scenes in the rarely used passive, rather than the more common active, syntax ("the cookie was eaten by the girl", rather than "the girl ate the cookie"). Following this priming phase, the children were asked to describe several additional scenes without further instruction. Kidd found that children's prior performance on an ISL task (but not an explicit learning task) predicted whether they would continue to use the passive sentence structure, demonstrating a link between ISL ability and the acquisition (and later use) of a novel syntax (Kidd, 2012). A subsequent study demonstrated that 6 to 8-year-olds' ISL task scores also predicted their comprehension of information presented to them using unfamiliar syntactic forms (Kidd & Arciuli, 2016).

An increasingly muscular body of evidence supports the idea that individual differences in ISL, in both children and adults, correlate significantly with various aspects of language skill. For example, Ellis and colleagues (2014) found that infants' ability to learn from the statistical regularities in picture sequences at 6 months old predicted both their receptive and expressive vocabularies at 22 months. This relationship remained even when the quality of maternal speech input and the general cognitive maturity of the infant were controlled for (Ellis et al., 2014). Spencer et al. (2015) tested 553 children (aged 4 to 10) to investigate the relationship between ISL ability and the development of literacy-relevant knowledge and skills. Structural equation modelling revealed that the children's ISL performance accounted for a unique portion of the variance in their vocabulary, phonological processing ability and oral language skill (Spencer et al., 2015).

However, ISL is not just important for language development in childhood. Mirman and colleagues (2008) established a link between ISL segmentation ability and novel word learning in young adults who already possessed large vocabularies. In another study using adult participants, Christiansen and Tomblin (2010) found that individual differences in ISL were correlated with participants' ability to track and comprehend long-distance dependencies in natural language. ISL performance in adulthood has also been implicated in the processes of speech perception and comprehension. Conway et al. (2010) showed that implicit sensitivity to the statistical structure of sequences was associated with the ability to identify spoken words under degraded listening conditions. As long as the words to be identified were somewhat 'predictable' from the context of the sentence, the association between ISL and degraded speech comprehension remained intact after controlling for other linguistic abilities, attention, memory and non-verbal intelligence (Conway et al., 2010).

ISL may also play an important role in the processing of non-literal/figurative language. When confronted with novel metaphors, participants with higher ISL abilities were better able to determine rapidly whether or not the expressions had some meaning (Drouillet et al., 2018). Taken together, this body of evidence suggests that ISL remains relevant to language skill in the TD population from birth into adulthood.

Given the well-documented link between ISL and language ability in TD individuals, it is not surprising that researchers have also investigated a possible connection between impaired ISL and language deficits in clinical populations. The logical hypothesis here is that deficient ISL may help explain some of the language difficulties experienced in conditions such as dyslexia, language disorders and autism. In the case of dyslexia, research findings have been mixed. While numerous studies have reported ISL deficiencies in dyslexic participants, others found no such evidence. Because of this discrepancy, Lum and colleagues (2013) performed a meta-analysis of 14 studies that investigated ISL in dyslexic participants using serial reaction time tasks. Their analysis revealed that ISL performance was significantly poorer in people with dyslexia than in TD controls (Lum et al., 2013). A similar meta-analysis was conducted by van Witteloostuijn et al. (2017), this time incorporating 13 dyslexia studies that utilised visual artificial grammar learning tasks to measure ISL. Again, ISL was impaired significantly in participants with dyslexia, with children affected to a greater extent than adults. The authors were keen to highlight, however, that a publication bias towards studies that found a significant connection between ISL and dyslexia may have swayed the outcome of their analysis (van Witteloostuijn et al., 2017).

Evidence also largely supports ISL's role in language disorders, where two meta-analyses found robust ISL differences between individuals with Developmental Language Disorder (DLD, formerly Specific Language Impairment; language difficulties in the absence of any other learning deficits) and those without (Lammertink et al., 2017; Obeid et al., 2016). Eligibility criteria for Lammertink et al.'s meta-analysis required studies to have tested and controlled for non-verbal intelligence, while the Obeid et al. (2016) study was notable for including studies that used a broad range of ISL measures.

Of particular interest in the field of language disorders is ISL's role in the processing and learning of non-adjacent dependencies; structural regularities in language that are separated by one (or often more) elements. For example, in English, non-adjacent dependencies exist between subjects and verbs (e.g., "the <u>trees</u> [in the park] <u>are</u> tall" vs "the <u>tree</u> [in the park] <u>is</u> tall"). However, a vast range of intervening elements, combined in almost unlimited ways, could occur between non-adjacent dependencies (e.g., the <u>trees</u> [between the armadillo sculpture and the sinister antique store] <u>are</u> tall"). For this reason, non-adjacent dependency-tracking is thought to be fundamental for syntax acquisition and, therefore, the correct construction and comprehension of more complex sentences (Erickson & Thiessen, 2015). Language impairments, which are often characterised by problems with grammar and syntax, often coincide with a reduced ISL capacity for tracking and learning non-adjacent dependencies (Iao et al., 2017; Lammertink et al., 2020).

While the balance of evidence appears to support a role for reduced ISL in dyslexia and DLD, the same cannot be said for autism. Although language difficulties are often present in ASD (Boucher, 2003), few studies have documented significant autism-related deficits in ISL ability. Indeed, many studies have reported that ISL remains intact in those with autism. This includes the previously cited meta-analysis by Obeid et al. (2016), which actually compared ISL performance differences between SLI and ASD. Obeid et al. concluded that, while impaired ISL may account for the language difficulties associated with SLI, it did not account for the communication problems observed in ASD[2]. As the interpretation of such findings is a central topic for this thesis, it is explored in greater detail later in this introductory chapter.

1.4. Social development and ISL

While ISL's role in language learning is now well documented, far less is known about how ISL might facilitate social skill development. In fact, although the two have long been associated in the literature, evidence directly linking ISL to social learning is actually

[2] Some individuals with ASD are known to exhibit the structural language impairments characteristic of SLI (Tager-Flusberg, 2006). Similarly, a subset of individuals diagnosed with SLI showed evidence of the social/pragmatic difficulties common in ASD (Durkin et al., 2012). The extent of the overlap between conditions remains a subject of debate, but it has been suggested that ASD and SLI share common aetiological factors (Leyfer et al., 2008). Given the potential overlap between conditions (and the finding that ISL deficits are often implicated in SLI) one might expect to see evidence of ISL deficits in ASD. However, many studies have detected no such deficit. ASD represents a highly heterogeneous group though, with profiles varying even within the minimally verbal population (Chen, Y. et al., 2024; Pizzano et al., 2024). Several additional factors, including motor/oral motor difficulties (Belmonte et al., 2013) may affect language development in autism.

quite scarce. In past decades, it would seem that ISL was implicated in social learning almost by default: social development must rely on implicit processes because social information (with its infinite variety and complexity) would be too difficult to process explicitly. For example, during social interactions it may be possible to assess someone's true intentions by analysing their facial expression, body language, choice of words and tone of voice. However, it would be slow, inefficient and exhausting to analyse this information at the conscious level. Instead, ISL is thought to enable learners to discover underlying statistical regularities in the actions of others, allowing them to make rapid sense of dynamic social environments. Because of its proposed role in social cognition, ISL has long been touted as the cognitive mechanism underpinning social intuition (Lieberman, 2000). More recently, empirical support for this claim has begun to emerge.

Just as ISL is capable of segmenting fluent speech into words (Saffran et al., 1996), it is also capable of identifying sequences of human body movements (Jurchiș & Dienes, 2023; Norman & Price, 2012) and detecting the segmental structure within dynamic human actions (Baldwin et al., 2008). Recently, Mermier and colleagues (2022) extended this finding to include social cues. Infants were found capable of segmenting the behaviours of two people interacting socially by implicitly learning the transitional probabilities within their facial expressions and looking behaviour. Such findings are important. Identifying distinct acts within others' actions is a fundamental requirement for learning about the motivations and consequences of observed behaviours. It is also thought to help humans successfully predict the actions of others in real-world social situations (Thornton & Tamir, 2021). Action segmentation is also thought to play an important role in attaching linguistic descriptions to witnessed events (Baldwin et al., 2008). For example, while a child watches someone play frisbee in a park, ISL may allow the segmentation of the player's dynamic motion into distinct *run – jump – catch – throw* acts, allowing the child to match these actions to their appropriate words.

In a similar vein, it has also been suggested that ISL may help lay the foundations for 'theory of mind' (ToM) in young children. Ruffman and colleagues (2012) argued that, before infants understand others' mental states, ISL allows them to analyse patterns of behaviour, pair mental state words with people's actions and provides an effective means for predicting others' behaviour. A young child may learn implicitly that positive outcomes (for example, a game of peek-a-boo) frequently follow the appearance of a smiling adult. The infant cannot yet infer the mental state of that adult but can nevertheless predict that a smiling person is likely to act in a positive way. Ruffman et al. suggested, therefore, that ISL provides infants with a stopgap understanding of the social world that may bootstrap their later development of theory of mind (Ruffman et al., 2012).

Limited support for a direct link between ISL ability and increased social understanding comes from eye-tracking evidence that adults with high ISL performance were the most sensitive to social context when predicting upcoming actions (Monroy et al., 2017). However, while a plausible theoretical argument exists for ISL's role in social skill development, the direct relationship between the two remains largely (and surprisingly) unstudied.

1.5. Autism Spectrum Disorder

As described earlier, autism is a lifelong condition characterised by communicative and social impairments. While autism has underlying genetic and neurological origins, it is currently diagnosed using behavioural indicators of social communication deficiencies together with evidence of restricted interests and repetitive behaviours (American Psychiatric Association, 2013). Around 1-2% of children meet the diagnostic criteria for ASD (Centers for Disease Control and Prevention, 2014; Kogan et al., 2009; Morales-Hidalgo et al., 2018; Zablotsky et al., 2015), with these individuals more likely than their TD peers to encounter serious difficulties with early language acquisition (Boucher, 2003). Despite extensive investigation, no single theoretical framework has yet emerged that can account for all of the symptoms associated with autism. However, theoretical accounts explaining ASD as a ToM deficit (Baron-Cohen et al., 1985a), a problem with 'weak central coherence' (Frith, U. & Happé, 1994) or as an extreme cognitive preference for 'systemising' (Baron-Cohen, 2009) are not mutually exclusive and have provided useful insights that have guided research. An additional theoretical possibility is that deficient ISL could be an important factor in the reduced social and language skills typically observed in ASD (Mostofsky et al., 2000). If it exists, an ISL deficit could underlie, exist alongside or indeed be caused by other neurological or cognitive atypicalities associated autism. Whatever the case may be, it is important to gain a better understanding of ISL's role in ASD, not least because implicit learning is the foundation for numerous interventions used with autistic children. Approaches such as Pivotal Response Training (Koegel et al., 1999), the Early Start Denver Model (Dawson et al., 2010), Pre-school Autism Communication Therapy (Pickles et al., 2016) and Joint Attention, Symbolic Play, Engagement & Regulation-JASPER (Kasari et al., 2021, 2023) all attempt to teach autistic children language and social skills without explicit instruction, thereby relying on children's ability to learn implicitly. Clarity regarding the extent to which ISL is preserved in ASD is therefore not just of theoretical importance. A better understanding could also guide the continued development of interventions for autistic children.

1.5.1. ISL and autism: The evidence so far

While somewhat limited in number, a handful of studies implicate ISL in autistic symptomatology. For example, Klinger and Dawson (2001) found that participants with ASD performed below the level of TD participants on an implicit category learning task. Evidence from brain imaging studies also appears to support the existence of autism-related ISL deficiencies. Scott-Van Zeeland et al. (2010) used functional magnetic resonance imaging (fMRI) to show that children with ASD (unlike TD children) showed no evidence of the neural correlates of ISL when listening passively to an artificial language.[3] However, Scott-Van Zeeland et al.'s study design did not allow for the monitoring, testing or control of participants' attention while they listened to the stimuli. This problem was addressed by Jeste et al. (2015), who used EEG to investigate the electrophysiological correlates of passive visual ISL in children with autism. Because Jeste et al.'s task required participants to attend to a visual display, the researchers were able to control for overt attention after monitoring participants' looking behaviour. While attention to the stimuli was similar for TD and autistic participants, the children with ASD showed reduced evidence of implicit learning as indexed by N1 (early visual

[3] When exposed to artificial language speech streams, typically developing children showed the expected increased activation in the left supramarginal gyrus, left inferior parietal lobule and bilateral striatum. However, no equivalent signal increases were detected in the ASD group. This finding indicated an autism-related atypicality in the neural architecture that subserves implicit language learning.

discrimination) and P300 (detection of novelty) event-related potentials (Jeste et al., 2015).

In a more recent study, Bettoni et al. (2021) investigated the relationship between parents' dimensional (and subclinical) autistic traits and their infants' performance on a visual habituation ISL task. In line with findings that autistic traits are highly heritable (Courchesne et al., 2020; Ronald & Hoekstra, 2011), the offspring of 'high autistic trait' parents were poorer at learning the statistical structure embedded in a visual sequence than the offspring of 'low autistic trait' parents. Several other studies have also demonstrated subtle ISL performance differences between autistic and TD individuals. For a review, see Eigisti and Mayo (2011).

However, while a relatively small number of studies demonstrated significant autism related ISL deficits, a substantial body of research found that autistic and control participants performed similarly on a wide range of implicit learning measures. These measures included speech stream/artificial language (Mayo & Eigsti, 2012), contextual cueing (Kourkoulou et al., 2012), serial reaction time (Izadi-Najafabadi et al., 2015; Nemeth et al., 2010), artificial grammar and probabilistic classification (Brown et al., 2010) tasks. Furthermore, two meta-analyses found that the equivalence of ASD and TD participants' ISL performance appeared stable across task modalities (visual, auditory and motor), leading researchers to conclude that implicit learning remains intact in autism (Foti et al., 2015; Obeid et al., 2016). However, several potentially confounding factors, which are discussed in the following sections, should be considered before this conclusion can be accepted.

1.5.2. Overuse of high-functioning autistic participants

Firstly, most ISL tasks are relatively taxing, requiring participants to comprehend and follow precise instructions and to sustain their attention throughout numerous trials. In the case of the serial reaction time (SRT) task, an oft-used tool in ISL research, an additional requirement is that participants possess sufficient sensory motor skill to respond quickly and accurately with key presses. These attentional and sensorimotor requirements have important consequences for the type of autistic participant who is able to complete such tasks. Take, for example, Nemeth et al.'s (2010) study of ISL in autistic participants, which used an alternating SRT task. During this task, a stimulus appeared at one of four empty circles on screen. Participants had to watch for the stimulus and respond by pressing one of four corresponding keys on a keyboard as quickly as possible. Unbeknownst to the participants, the locations of stimuli followed a predefined pattern, interspersed with stimuli in random locations. Alternating sequenced and random stimuli in this way is known to reduce participants' explicit knowledge of the 'hidden' sequence. Throughout an alternating SRT task, the difference in reaction times between patterned and less predictable stimuli gives a measure of how much implicit learning has taken place. The learning phase of Nemeth et al.'s task took around 35 minutes and required 1,700 key presses from participants. Brown et al. (2010) used a similar task that required participants to respond 1,008 times.

Given the duration and relative difficulty of such tasks, it is no great surprise that the vast majority of 'ISL in autism' studies have recruited participants with high-functioning autism (HFA) or Asperger syndrome[4]. Such participants usually have average to high intelligence and are often IQ-matched in studies to TD controls. This bias is entirely understandable. Those at the higher-functioning end of the autistic spectrum are the best able to comprehend and follow the experimenter's instructions while maintaining concentration throughout the testing process. Furthermore, controlling for IQ does seem an eminently logical precaution when investigating learning mechanisms in general. However, studying ISL using only high-functioning autistic participants does present several empirical difficulties.

Evidence suggests that people with ASD tend to employ intentional, explicit learning strategies in situations that would typically elicit implicit processing (Klinger et al., 2007). These situations may include tasks, such as the SRT, that were developed to assess ISL. Zwart and colleagues (2017) monitored event-related potentials (ERPs) as autistic adults and TD controls completed a SRT task. As demonstrated in numerous other studies, sequence learning (as measured by changes in reaction time) was similar for the ASD and control groups. However, ERP analysis revealed that learning in the ASD group was characterised by an enhanced frontal P3 component, which the authors related to controlled, intentional learning. Conversely, the control group's learning was

[4] At the time of writing, Asperger Syndrome, or Asperger's, is not diagnosed as a separate condition to autism (American Psychiatric Association, 2013). Historically, the principal difference between Asperger's and autism was that the former typically featured an absence of language delays alongside milder autistic symptoms.

characterised by an enhanced N2b component, indicating automatic (implicit) learning. Therefore, while the majority of recent studies have found ISL task performance to be equivalent for autistic and TD participants, it is possible that the underlying cognitive mechanisms employed by the two groups are entirely different. A follow-up study by Zwart et al. (2018) found that performance on a *deterministic* sequence SRT task, designed to elicit *explicit* processing, was correlated positively with social impairment in autistic adults but not in TD adults. In other words, for autistic adults, better explicit processing was associated with *poorer* social functioning. Zwart and colleagues speculated, therefore, that overuse of explicit learning strategies *may* harm social communication development in autistic individuals, whether or not a fundamental ISL deficit exists.

The finding that autistic participants may be achieving TD-equivalent scores on ISL tasks using explicit learning strategies becomes particularly problematic when one considers the relationship between explicit learning and intelligence; explicit learning is highly correlated with intelligence whereas ISL is not (Gebauer & Mackintosh, 2007; Kalra et al., 2019; Reber, A. S. et al., 1991). Individuals with HFA, who are historically overrepresented in multiple fields of autism research (Jack & Pelphrey, 2017; Russell et al., 2019), often have average-to-high intelligence. This intelligence, combined with minimally impaired executive function (Hull, L. et al., 2021; Joseph & Tager–Flusberg, 2004; Landa & Goldberg, 2005), may allow HFA participants to use explicit strategies with some degree of success. However, this capacity may not exist throughout the autistic population, within which intellectual disabilities are common (Dykens & Lense, 2011; Vivanti et al., 2013). It is important, therefore, that implicit learning research should include lower-functioning autistic participants, to examine how ASD symptom severity and lower levels of intellectual functioning affect ISL task performance.

1.5.3. Absence of younger autistic participants

As described earlier, the majority of studies have found that autistic participants perform no differently on ISL tasks than do controls. However, it is not only lower-functioning ASD participants that have been missing from these trials. The vast majority of studies have, so far, also neglected to recruit the youngest school-aged children as participants. For example, in the 13 studies that met the selection criteria for Obeid et al.'s (2016) meta-analysis, only one recruited any children with ASD under 7 years old. This particular study did detect an ISL deficit in the ASD group, though with only 11 autistic participants this result might not generalise to the wider autistic population (Mostofsky et al., 2000).

As discussed earlier, ISL ability (while far less age dependent than explicit learning) is still thought to mature throughout childhood, achieving adult equivalence around the age of 10 (Finn et al., 2016) and potentially peaking at around 12 years old (Janacsek et al., 2012). It is a theoretical possibility, however, that the maturation of ISL proceeds more slowly in those with ASD, achieving TD-equivalence later in life. A delayed yet normal developmental endpoint of ISL could explain why so many studies have found ISL to be intact in their (older) autistic participants. Because early childhood is such an important period for language development (Rescorla, 2005), an implicit learning delay at this stage could harm social communication development significantly. It is important, therefore, that ISL research includes younger autistic participants. This extension of testing to younger children would help to establish whether ISL follows different developmental trajectories in ASD and TD populations. Longitudinal study designs, which could track individual children's ISL performance over time, seem particularly well-suited to answering this question.

1.5.4. Reduced social attention

The initial study in this thesis is predominantly focused on ISL ability, and how it might influence language and social development in those with autism. However, it is also important to consider another factor that could shape autistic children's development significantly: the extent to which they attend to (and seek out) social stimuli. In TD infants, stimuli with social importance are usually granted attentional priority over non-social stimuli. For example, TD newborn babies have been shown to orient towards images of human faces in preference to images of scrambled, distorted faces (Salva et al., 2011). Similarly, highly relevant social signals, such as direct eye contact, preferentially capture attention in neurotypical children and are known to activate areas of the brain involved in social interaction (Senju & Johnson, 2009). Dubey et al. (2022) also demonstrated a significant positive relationship between TD children's preference for viewing social stimuli (over non-social stimuli) and parents' ratings of their child's social aptitude.

Compared to typically developing infants, autistic children are known to be less attentive to social stimuli from a very early age. From the age of two months onwards, attention to others' eyes has been shown to decline in children who are later diagnosed with ASD (Jones, W. & Klin, 2013). Reduced social orienting, in a natural setting, has also been detected in infants who later received an autism diagnosis. In an analysis of first birthday party video footage, children with ASD looked less often at others, and oriented less often to their name being called, than both TD infants and infants later diagnosed with non-ASD-related intellectual disabilities (Osterling et al., 2002). Indeed, evidence from a range of experimental paradigms indicates that those with ASD are less likely than TD individuals to automatically prioritise attention towards socially relevant aspects of their environment. In a meta-analysis which reviewed data from 188 studies, Hedger and colleagues (2020) found robust evidence for reduced social orienting and, to a lesser extent, for reduced social seeking behaviour in people with ASD.

It has been suggested that a fundamental reduction in 'motivation' to attend to social stimuli may be a significant contributor to the social communication and language difficulties common in autism (Chevallier et al., 2012). The Social Motivation Theory (SMT) argues that autistic children, from the moment they are born, find socially relevant stimuli (such as eye-contact, speech and facial expressions) inherently less rewarding than do TD infants. Because social contact does not stimulate autistic infants to the same extent as TD children, Chevallier et al. suggest that autistic infants are less likely to attend to (or engage in) social interactions. As a consequence, children with ASD are thought to experience fewer social and language-learning opportunities than their TD peers. Chevallier et al. argue that it is this relative inexperience in social interaction (rather than a cognitive deficit that prevents learning) that leads to the social communication difficulties common in autism (Chevallier et al., 2012).

Vivanti and colleagues (2013) proposed a similar argument for the development of intellectual disabilities (ID) in people with ASD. Based on research conducted between 2000 and 2008, an estimated two thirds of autistic individuals had an ID (Dykens & Lense,

2011) and debate is ongoing as to how the two conditions may be related.[5] Because autism can undoubtedly occur in the absence of ID, autism and ID were historically regarded as a largely independent conditions, albeit ones that are frequently comorbid. However, another possibility is that the early presence of autistic symptoms (such as diminished attention to social stimuli) reduces children's access to the type of input required for 'typical' brain development, with more severe early autistic symptoms acting as a risk factor for the subsequent development of ID.

Vivanti et al. (2013) conducted a longitudinal study which showed that young children with greater ASD symptom severity were indeed more likely to present with ID 2 years later, regardless of initial cognitive level. Similar to Chevallier et al. (2012), Vivanti and colleagues proposed that:

> *a decrease in the attentional and processing weight assigned to social information, in children with ASD, might preclude the usual social experiences that are necessary for "normal" cognitive development during early sensitive periods… If infants with ASD do not have access to the appropriate input that supports the efficient organization and specialization of the brain in neurotypical development, this might ultimately result in the child also having an ID. A corollary of this model is that the more severe the ASD symptoms, the more the child would be "at risk" for developing an ID'* (Vivanti et al., 2013, p. 2).

Theories of this type are far from universally accepted. For example, Jaswal and Akhtar (2019) have criticised the SMT on a number of levels. They argued that many common autistic childhood behaviours, such as low levels of eye contact and infrequent pointing, could be explained equally well without reference to diminished social motivation.

[5] Between 1998 and 2018, there was an exponential increase in recorded autism diagnoses in the UK (Russell et al., 2022). Throughout this period, there also existed a trend for diagnosing autism in older individuals with higher cognitive ability and/or less severe autistic traits (Arvidsson et al., 2018; Russell et al., 2022). It is therefore likely that ID and ASD currently co-occur less frequently than earlier estimates suggest.

Jaswal and Akhtar also highlighted the numerous testimonies of autistic self-advocates who directly state their desire to engage in social interactions and to develop social relationships (Jaswal & Akhtar, 2019). However, the SMT posits only that intrinsic interest in social stimuli is reduced in ASD (not eliminated) and that this can have important downstream consequences for social communication development (and perhaps for broader intellectual development). Support for such a mechanism comes from several lines of converging evidence.

Clements et al. (2018) performed a systematic review of MRI studies that examined reward processing in ASD. They found that autistic individuals showed evidence of atypical processing of both social and non-social rewards. Clements et al. further suggested that this aberrant reward processing may not only lead to diminished motivation for social interaction but may also explain the increased attention granted to the (non-social) restricted interests commonly observed in ASD (Clements et al., 2018). Another study, by Klein and Dial (2020), found that ASD-related underperformance on some ISL tasks may even be caused by underlying attentional dysfunctions. In an eye-tracking study, autistic participants and TD controls completed a cartoon animal implicit category learning task. While the autistic participants were slightly less able to learn the prototypes than were the control group, this deficit may have been mediated by differences in visual attention. Klein and Dial observed large differences in eye gaze patterns between the two groups, including fewer fixations by autistic participants to the faces of the cartoon characters. It is possible, therefore, that atypical allocation of attention may result in autistic individuals missing critical social input that would otherwise facilitate implicit learning (Klein & Dial, 2020). A related effect was reported by Gray and colleagues (2018), who showed that autistic and non-autistic individuals also differed in the very early stages of visual and attentional processing. Gray et al. investigated the processing of socially rewarding visual scenes using continuous flash suppression (CVS). During CVS, target visual stimuli are presented to participants at a level initially below the threshold of awareness. The time it takes for participants to become explicitly aware of the target gives an indication of the stimuli's salience. Gray et al. found strong evidence that rewarding visual social scenes were granted privileged access to awareness in TD, but not autistic, adults. In support of SMT, Gray et al. suggested that, if this diminished access to explicit awareness extended to subtle real-world social signals, people with autism may miss many social learning opportunities that would otherwise support typical development.

Finally, SMT makes an important prediction: If impaired social cognition is a consequence (rather than a cause) of reduced social attention, autistic participants' performance on socially relevant tasks should improve if they become more motivated to attend to social stimuli. Research appears to tentatively support this hypothesis. As discussed earlier, ASD is associated with reduced orientation to eyes and faces. Autistic individuals are also less likely to shift their attention to where others are looking (Nation & Penny, 2008). However, Ristic et al. (2005) demonstrated, in a gaze cuing study, that if (and only if) gaze direction had predictive value that made it useful to complete a task, HFA participants attended to it closely. Conversely, TD participants consistently attended to gaze cues whether or not they aided task performance (Ristic et al., 2005). Therefore, while people with autism may not spontaneously follow gaze cues in social situations (in which gaze may be one of many competing stimuli), they did so just as readily as TD participants when the relevance of eye direction was enhanced.

Another proposed way of 'boosting' the relevance of social cues is to simply provide explicit instruction that directs participants' attention toward them. Many studies have demonstrated that autistic individuals often have difficulty understanding figurative language, which carries nonliteral meaning beyond what is explicitly stated (Kalandadze et al., 2018). Wang et al. (2007) monitored brain activity (via MRI) in autistic children while they viewed short cartoons containing ironic or non-ironic remarks. Compared to TD controls, the ASD group showed reduced activity in the medial prefrontal cortex and right superior temporal gyrus, brain regions known to be important for social cognition. However, when given explicit instructions to focus on facial expressions and tone of voice (cues known to aid understanding of non-literal language) the autistic participants showed increased activation in these brain areas. Because the cartoons used were overly simple, both groups were similarly able to identify ironic remarks with ease. However, the study did demonstrate that a simple instruction to attend to social cues was sufficient to normalise brain activation in children with autism (Wang et al., 2007).

Taken together, these studies suggest that it may be unwise to simply accept the view that social and language difficulties in ASD are caused by fundamental deficits in cognition. Instead, atypical reward processing and diminished attentional prioritisation towards social stimuli may promote the social communication impairments associated with the autism phenotype. If ISL *is* found to remain fully intact in ASD, it remains unlikely that children would readily acquire complex language and social skills if they rarely attended to these aspects of their environment. Reduced social orientation will therefore be considered as a supplementary, or even alternative, hypothesis for diminished social communication learning throughout this thesis.

1.6. Task design considerations

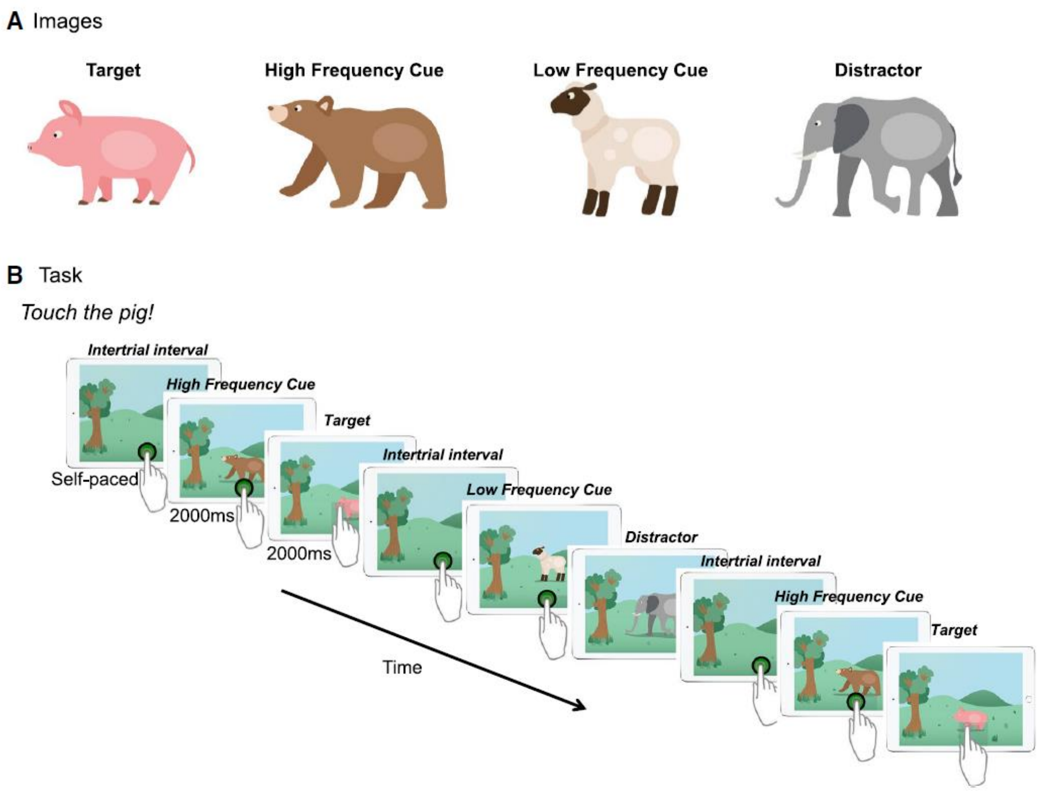
As discussed previously, the majority of studies on implicit learning in autism have used older children and adult participants, most of whom were high functioning. Such studies have generally found no difference in ISL ability between ASD and TD participants. Aside from the obvious conclusion that ISL is not deficient in autism, this result leaves open the possibilities that: a) studies have failed to detect ISL deficits in older participants because deficits are only present in younger children, and b) HFA participants were able to deploy explicit (rather than the intended implicit) learning strategies to achieve TD-like performance on ISL tasks.

One recent study attempted to address these two issues. Jones et al. (2018) tested 2-to-8-year-olds, with varying ASD symptom severity, using a simplified version of a visual SRT task (see **Figure 1**). Their task consisted of discrete trials, each made from a two-image sequence. At the beginning of each trial, one of two cue images appeared on screen. The cue was then followed by either a target image which the child had to touch as quickly as possible, or a distractor image which the child was told not to touch.

Unknown to the participants, one of the cue images (the high-frequency cue) was followed by the target on 75% of trials and by the distractor on 25% of trials. The reverse was true for the other cue image (the low-frequency cue). To quantify implicit learning, Jones et al. examined the difference in reaction times between high- and low-frequency cued trials as testing progressed. Multivariate classification analyses revealed that, while the majority of autistic children performed similarly to TD participants, a subset of the children with more severe ASD symptoms showed reduced ISL task performance. The study was not designed to show if this was caused by an implicit learning deficit per se, or by autistic children's unsuccessful attempts to apply explicit learning strategies. Nevertheless, Jones et al.'s study suggests that ISL research with younger children, of varying ASD severity and intelligence, is not only possible but a worthwhile area for further investigation.

Figure 1

Visual ISL task employed by Jones et al. (2018)



Note. The cartoon animals seen here are representative placeholders. The study actually used images from popular cartoons and movies. Permission to reproduce this figure was granted by Springer Nature.

Building on the work of Jones et al. (2018), the first study in this thesis also aimed to investigate ISL in young, lower-functioning autistic children. Changes to the ISL task design are described in detail in the following chapter. However, it is worth mentioning here a final factor which complicates research into ISL in autism yet further: the efficacy of explicit learning strategies is known to depend on the complexity of the task at hand. While intentional (explicit) processing is known to be effective for learning simple sequences, the additional cognitive load of 'trying to learn' when the task is sufficiently complex has been shown to harm learning performance (Finn et al., 2014; Fletcher et al., 2005; Howard & Howard, 2001). Tasks such as the SRT (though too taxing for many autistic individuals) present participants with sequences that are far simpler than the almost infinite combination of sounds in natural language or variables in real-world social interactions. Indeed, Zwart et al. (2018) called into question the ecological validity of the traditional SRT task as an ISL measure, as the deterministic sequences used may be simple enough to allow participants to employ explicit learning strategies successfully. A similar argument could be made for the task developed by Jones et al. (2018). Discrete, self-paced trials, each consisting of just a two-image sequence, could conceivably facilitate explicit learning in any participant with a preference for learning in this way. Unfortunately, Jones et al. were not able to report data on participants' explicit awareness of the underlying task structure, so the ecological validity of their task is difficult to ascertain.

However, this requirement for increased ecological validity raises an important consideration for the studies conducted as part of this thesis. The statistical learning required when undertaking ISL tasks should ideally be challenging enough to (at least partially) reflect the complexity that individuals face in the real world. Traditional SRT tasks employ repeated deterministic sequences that are conducive to explicit processing (Zwart et al., 2018). Alternating serial reaction time (aSRT) tasks also employ repeated deterministic sequences. However, aSRT tasks intersperse the sequences with random stimuli to reduce the chance of participants developing explicit awareness. In some aSRT tasks, blocks of deterministic 'test' sequences are alternated with blocks of random stimuli. In others, individual stimuli from the deterministic sequence are alternated with random stimuli (for example, if the test sequence was 1-2-3-4, participants would be presented with 1-R-2-R-3-R-4-R, where R is a random stimulus). However, one could question the ecological validity of *any* task that uses deterministic sequences. In the first type of aSRT task, the sequence to be learned is still (relatively) short and invariant, even if it is alternated with blocks of random stimuli. In the second type of aSRT task, the sequence is effectively presented as a series of deterministic non-adjacent dependencies, so could be considered even less representative of real-world variation.

To avoid this concern, the ISL task employed in the first study abandons deterministic sequences in favour of a non-repetitive sequence governed by underlying transitional probabilities. The addition of a sequence further extends the method used by Jones et al. (2018). In their study, a high-frequency cue image (bear) was followed by the target (pig) on 75% of trials and by the distractor (elephant) on 25% of trials. However, sequences were only ever two stimuli long (bear or sheep followed by pig or elephant). In Study 1 (see Chapter 2), similar transitional probabilities were employed to create a continuous sequence of stimuli. Learning on this new task therefore required the same implicit learning of underlying statistical transitions as Jones et al. However, the continuous feed of stimuli better reflected the type of input experienced in the real world, for example the fluent speech from which infants are required to extract individual words. The use of a continuous probabilistic stimuli stream does not exclude the possibility of participants attempting explicit processing strategies. However, it does remove the opportunity for participants to explicitly learn a particular sequence of stimuli (whether it is disguised by additional random stimuli or not). These changes were implemented to make the novel task a more ecologically valid measure of ISL.

1.7. Summary

Implicit statistical learning is the cognitive process that allows the extraction of regularities in the environment over time, without conscious awareness or an intention to learn. Evidence suggests that ISL is particularly important for the acquisition of language and social skills, especially in early childhood. Because ASD is partly characterised by social communication impairments (often alongside language difficulties), it has been suggested that a deficit in ISL may play a significant role in the reduced social communicative skills typical of autism. However, while a few studies found evidence of ISL impairment in those with autism, a large body of evidence showed no difference between ASD and TD participants on a wide range of implicit learning measures. Evidence suggests, therefore, that ISL remains intact in autism. There are, however, several significant complications to this conclusion, which this thesis planned to investigate.

Firstly, almost all existing research on ISL in ASD has focused on older children and adults. It therefore remains a possibility that ISL reflects a cognitive ability that matures more slowly in those with ASD, achieving TD-equivalence only in later childhood. Furthermore, studies so far have focused on participants with high-functioning autism. This is a concern because of the potentially confounding effects of high intelligence, an ASD-related propensity to over-use explicit learning strategies and the relative simplicity of ISL tasks. These shortcomings in current research are summarised as follows:

- While people with HFA have average to high measured intelligence, this is not the case for a large proportion of the autistic population.
- People with ASD are thought to apply intentional, explicit learning strategies to tasks which would typically be solved implicitly.
- The efficacy of explicit learning strategies depends on the complexity of the task at hand. Conscious efforts to learn are known to harm learning performance if the task is sufficiently difficult.
- The learning requirements of laboratory-based ISL tasks are far less challenging than the learning requirements faced in the real world.
- Because participants with HFA have high intelligence, they may be able to apply explicit strategies during ISL tasks with a degree of success.
- This success may translate to a behavioural performance on ISL tasks equivalent to TD participants. However, the cognitive mechanisms employed by the two groups could be entirely different.
- Nevertheless, over-use of explicit processing in the real world (where the input to be learned from is far more complex) could still harm social communication development in ASD. This detriment to learning would remain even in the absence of an autism-related ISL deficit.

Research on ISL should therefore include not only younger, but lower-functioning autistic participants, to examine how age, symptom severity and cognitive deficits affect ISL task performance. Finally, this thesis aims to examine the role of social orientation in language and social skill learning. It is possible that atypical allocation of attention could cause autistic individuals to miss critical social input that would otherwise facilitate implicit learning. The influence of reduced social attention will therefore be considered alongside ISL when evaluating social communication development in relation to autism.

Note to the reader: As mentioned in section 1.1, this chapter served to summarise our current understanding of ISL (and its relationship to autism) and to present the rationale for Study 1, the subject of the following chapter. Because COVID social distancing measures disrupted Study 1 and the studies that were initially intended to follow it, a second introductory chapter can be found later in this thesis. This second chapter introduces a new series of studies that investigated the implicit learning of social information (in TD and autistic adults) and its relation to dimensional autistic traits.

Chapter 2. Study 1: Implicit statistical learning in young, lower-functioning autistic children

2.1. Introduction

As described in Chapter 1, numerous studies have demonstrated that autistic and TD participants perform similarly on various ISL tasks, suggesting that ISL remains intact in ASD (Foti et al., 2015; Obeid et al., 2016). However, the interaction of several confounding variables mean that it cannot yet be concluded whether this is truly the case. Firstly, most ISL tasks are unsuitable for testing younger, lower-functioning autistic participants. Therefore, the majority of studies in this field have recruited older participants with high-functioning autism, who have average to high intelligence. Autistic individuals may employ intentional, explicit learning strategies during tasks that are intended to assess ISL (Klinger et al., 2007; Zwart et al., 2017). Because explicit learning is closely linked to intelligence (Gebauer & Mackintosh, 2007; Reber, A. S. et al., 1991), many studies may have unintentionally recruited the very subset of the autistic population that are best able to achieve TD-equivalent ISL task performance using explicit strategies. It therefore remains unclear whether lower-functioning children with ASD (who would be less able to compensate for reduced ISL with explicit strategies) would show evidence of reduced ISL if tested with a suitable task. Another possibility is that ISL development may be delayed in ASD, maturing to typical levels only in later childhood. Because early childhood is a critical period for language development (Rescorla, 2005), an ISL delay at this stage could contribute to the reduced communication skills often observed in those with autism. Study 1, with its original (pre-COVID) longitudinal design, was designed to investigate these two possibilities.

As summarised in Chapter 1, an earlier study by Jones et al. (2018) attempted to resolve these issues by designing an ISL task suitable for younger, lower-functioning autistic children. Jones et al. used a simplified version of a SRT task which was administered using a touchscreen tablet computer. At the start of each experimental trial, one of two cue images appeared on screen. The initial image was followed 2000ms later by either a target image, which the child was required to touch as quickly as possible, or a distractor image, which the child was told not to touch. Unbeknownst to participants, whenever the 'high-frequency cue' appeared, it was followed by the target on 75% of trials and by the distractor on 25% of trials. When the low-frequency cue appeared, it was followed by the target on 25% of trials and by the distractor on 75% of trials. Participants activated each trial by holding down a button at the bottom of the screen. The discrete two-image trials were therefore self-paced, with the location of the child's finger standardised before each reaction time (RT) was recorded. The task was also simple enough for younger, lower-functioning autistic children to understand: 'place your finger on the button, then touch the target picture when it appears'. Compared with a traditional SRT task, Jones et al.'s task placed lower sensorimotor demands on participants, recording RTs as they touched a single large target picture on screen (rather than one of several keyboard keys). Jones et al.'s participants also completed a maximum of 168 trials, far fewer than the 1000+ responses required during Brown et al.'s (2010) and Nemeth et al.'s (2010) SRT tasks.

To assess participants' ISL ability, Jones et al. monitored the difference in RTs between high- and low-frequency cued trials as testing progressed. In line with previous research, most of the autistic children performed similarly to TD participants. However, some of the children with more severe ASD symptoms showed evidence of reduced ISL (Jones, R. M. et al., 2018).

2.1.1. ISL task modifications

As mentioned in Chapter 1, one aim of the current study was to build on Jones et al.'s work by creating a task that better reflected the complexity that autistic children might face in the real world. A potential criticism of Jones et al.'s task was that discrete self-paced trials (each consisting of just two stimuli) were highly conducive to the use of explicit learning strategies. However, it was important that the new task retained the functional simplicity that made Jones et al.'s task suitable for lower-functioning participants. As such, a similar touchscreen interface was retained, with participants again required to hold down an on-screen button before stimuli were presented. However, instead of discrete two-image trials, stimuli in Study 1 were presented in a continuous sequence governed by underlying transitional probabilities.

Similar to Jones et al. (2018), high- and low-probability cues (which predicted the appearance of the target 75% and 25% of the time respectively) were embedded in the sequence. Performance improvements during this novel task would therefore require the same implicit learning of underlying statistical probabilities as Jones et al. However, the continuous feed of stimuli was introduced to better represent sensory input in the real world, such as the fluent speech from which infants are thought to segment individual words. The continuous stimuli stream was also expected to reduce opportunities for explicit processing, helping to ensure that learning remained implicit.

An additional change was made to the way RTs were recorded. Many children with ASD not only have reduced social and language skills but often have motor abnormalities, such as poor timing and coordination of movements (Fournier et al., 2010). Those with ASD may have particular difficulties with physical acts such as catching (Ament et al., 2015) and grasping, and that this may be related to deficiencies in movement execution (Stoit et al., 2013). To reduce the effect of sensorimotor disturbances on autistic participants' RT measurements, response times were recorded in two ways. In a similar way to Jones et al., RTs were recorded as the time taken to touch the target image. However, because touching the target required a fast, co-ordinated hand movement, ASD-related motor abnormalities may have introduced variability in recorded RTs. To reduce this effect, the novel ISL task also recorded the time taken for participants to lift their finger off the 'button' following presentation of the target. It was hoped that this additional method of measuring RT would reduce the influence of both general motor adaptation and ASD-related motor deficiencies on response times in order to better detect changes brought about purely by ISL. Pictures other than the target required no response from participants (their finger simply remained on the 'button') which further reduced the coordination requirements of the task.

2.1.2. Research questions and study design

As well as making modifications to the ISL task, the current study aimed to extend the reach of Jones et al.'s work to answer several additional research questions. As such, before COVID restrictions interrupted proceedings, Study 1 was intended to be longitudinal. All participants were to be tested twice, with an interval of 18-24 months between assessments. On both occasions, participants would have been tested directly for ISL ability, receptive vocabulary and non-verbal intelligence, while parents and teachers would complete separate assessments of each child's level of social communication. The current study's original research questions were as follows.

Is autism associated with reduced ISL performance? Jones et al. (2018) found that a subset of children with more severe ASD symptoms showed evidence of reduced ISL. The primary question of the current study was whether this finding could be replicated. Using an ISL task similar to Jones et al.'s, the current study tested whether reduced levels of implicit learning could be detected in younger, lower-functioning autistic children compared to TD age-matched controls.

Does ISL follow different developmental trajectories in ASD and TD populations? As discussed in Chapter 1, ISL is known to be less age-dependent than explicit learning. Nevertheless, implicit learning develops throughout childhood, achieving adult-like levels in the TD population between 10 and 12 years old (Finn et al., 2016; Janacsek et al., 2012). A small correlation between ISL task performance and age (and evidence of a shallow ISL development trajectory) might therefore be expected for TD participants in the current study. However, it is possible that ISL development is delayed in ASD, trailing TD levels earlier in life but still achieving adult-like levels by around 11 years old. Such a delayed yet normal developmental endpoint would provide one explanation for the finding that older autistic and TD participants performed similarly on ISL measures in a broad range of studies. If ISL development *is* delayed in this way, data might indicate that ISL follows a steeper developmental trajectory for autistic 4-to-11-year-olds compared to non-autistic age-matched controls.

Does ISL ability predict vocabulary? Multiple aspects of language development have been linked to implicit learning ability (Ellis et al., 2014; Spencer et al., 2015). ISL task performance, in the current study, was therefore expected to predict receptive vocabulary (in both TD and ASD groups), after controlling for non-verbal intelligence. It could also be argued that, if the developmental trajectory of ISL *does* differ between autistic and TD children, vocabulary acquisition might follow a similar pattern. While children with autism would be predicted to possess smaller vocabularies generally, the relative rate of vocabulary acquisition may increase more rapidly for autistic 4-to-11-year-olds compared to TD age-matched controls (as language learning is facilitated by ISL, which might be delayed in ASD). However, many other factors, including social attention and general intelligence, may also influence children's learning of new vocabulary.

Is ISL ability predictive of social functioning? If ISL facilitates the development of social understanding in children (Ruffman et al., 2012), better ISL task performance should be associated with better social communication, as assessed by children's parents and teachers. While the ASD group would be expected to exhibit more social difficulties than the TD group, a positive correlation between ISL ability and social functioning should be present for both autistic and TD children.

How do ISL, language and social impairment interact over time? By testing children twice, with up to two years between assessments, the current study intended to track ISL ability in individual children over time. The longitudinal design would also allow for an analysis of which measures at time 1 were significant predictors of social functioning and vocabulary at time 2. Of particular interest here would be the ability of ISL task performance to predict downstream development of language and social skills.

2.2. Method

Data collection for this study was interrupted at a critical stage by COVID-19 restrictions in the UK. Schools were closed, or remained open under highly restricted conditions, throughout much of 2020/2021. The closures meant that participant recruitment and testing, and the planned collection of data from parents and teachers, was not completed as intended. The effect of this early termination on the study is referred to throughout the following sections.

2.2.1. Ethics and consent

Approval for this study was granted by Nottingham Trent University's College of Business, Law and Social Sciences Research Ethics Committee. Fully informed written consent was obtained from all schools involved in the research. Parent/carer consent was obtained on a fully informed, opt-in basis and verbal assent was obtained from all participants prior to testing.

2.2.2. Participants

Due to COVID-related school closures, fewer participants took part in the study than intended. It also became impractical to continue with the planned second stage of the study's longitudinal design. In total, 36 participants (27 boys and 9 girls, aged 4 to 12 years old, mean age = 8, SD = 1.91) completed testing, all of whom were recruited from four special educational needs (SEN) schools and one mainstream primary school in the East Midlands of England, UK. Of these participants, nine children (8 boys and 1 girl, mean age = 10, SD = 0.86) had already received a diagnosis of ASD[6] and were receiving specialist government-funded educational support in line with a current Education, Health and Care Plan (EHCP). As will be discussed later, a further 30 children with autism were recruited to the study but were unable to complete the ISL task. These participants were excluded from further testing. The remaining 27 control group participants (19 boys and 8 girls, mean age = 8 years, SD = 1.83) were typically developing, had no current or pending EHCP and received no additional support in school for special educational needs.

To reduce potentially confounding effects on children's language and social skill attainment, participants were not recruited to the study if they spoke English as a second language, had a record of poor school attendance, had current or historical difficulties with their hearing or if they had been diagnosed with an additional condition (for example Down syndrome) known to affect children's social or linguistic development.

As will be mentioned in the following section, in the original study design, all participants would have been the subject of two separate ASD screening questionnaires: the Social Responsiveness Scale (Constantino, J. N. & Gruber, 2012) and the Social Communication

[6] In the UK, The National Institute for Health and Care Excellence (NICE) stipulates that children should be referred to a local authority multidisciplinary 'autism team' when a diagnosis of ASD may be required. Autism teams, which often include paediatricians, speech and language therapists and clinical/educational psychologists, are advised by NICE to conduct a comprehensive assessment of the child and to diagnose conditions with reference to ICD-10 (World Health Organization, 2016) or, since 2017, DSM-5 (American Psychiatric Association, 2013) criteria. Details of how and when participating children received their ASD diagnosis where not sought during the current study.

Questionnaire-Current (Rutter et al., 2003). Children would have been excluded from the TD control group if their Social Responsiveness Scale score was above 75 or if their Social Communication Questionnaire-Current score was above 15. Unfortunately, because schools closed abruptly due to COVID-19 restrictions, screening questionnaires were only collected for four children in total, all of whom were in the ASD group. Therefore, no TD participants were excluded for this reason.

2.2.3. Autism screening assessments

Each child participant would have been the subject of two ASD screening assessments:

The Social Responsiveness Scale (SRS-2, Constantino, J. N. & Gruber, 2012) was developed to identify ASD-related social impairment and to quantify its severity. The current study used the school-age form of the SRS-2 (suitable for children aged 4 to 18), which contained 65 items, all marked on a quantitative scale. A member of school teaching staff, who worked regularly with the child, completed the questionnaire without supervision. The scale's authors reported high internal consistency (0.96 when teachers completed the SRS-2) and that total scores were moderately to highly correlated with other well-established autism screening measures (Constantino, J. N. & Gruber, 2012). Other studies have also confirmed the SRS-2 to be an adequately reliable and valid measure of social behaviour atypicalities (Bruni, 2014; Nelson et al., 2016; Wigham et al., 2012). Because teachers were sometimes asked to complete multiple SRS-2 questionnaires (one for each participating child in their class), they were incentivised to return completed forms with up to £10 in Amazon vouchers (£5 for up to 3 questionnaires, £10 for 4 or more).

The Social Communication Questionnaire-Current (SCQc, Rutter et al., 2003) is a short parent-report ASD screening instrument suitable for evaluating anyone over four years old, as long as their mental age exceeds two years. The standard version of the Social Communication Questionnaire can discriminate reliably between autistic and non-autistic children (sensitivity = 0.9, specificity = 0.86), with outcomes unaffected by the child's IQ or by the parent's level of education (Chandler et al., 2007).

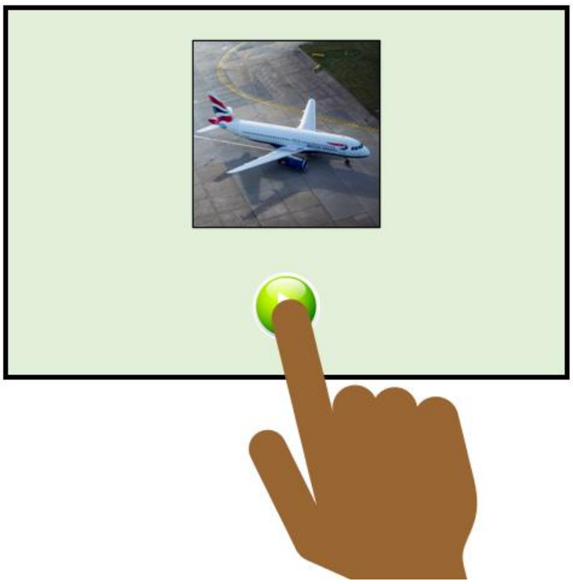
The 'Current' form of the questionnaire (SCQc), used in this study, asked 40 ‘yes or no’ questions about the child's social communication behaviour over the past three months. The SCQc is a less reliable screening instrument than the SCQ (Chesnut et al., 2017) but was designed to track changes in autistic symptom severity over time, making it a useful additional measure for this longitudinal study. Parents or primary carers completed the SCQc without supervision and were incentivised to return their completed forms with the offer of a £5 Amazon voucher.

2.2.4. Implicit statistical learning task and procedure

Implicit statistical learning was assessed using a novel visual serial reaction time task developed using PsychoPy (Peirce et al., 2019). Children performed the task on a Microsoft Surface Pro touchscreen computer. Because the task was designed to be accessible for young, lower-functioning autistic children, it was kept deliberately simple and brief. During play, children had to react as quickly as possible by ‘swiping’ a known target image on screen, while not reacting to any other images that appeared (see **Figure 2** for an illustration of the task interface).

Figure 2

Simple interface of the novel touchscreen ISL task



Note. Participants placed their finger on the ‘play button’ to activate stimuli presentation, then swiped the target image whenever it appeared.

Four images were used for any one participant: a target image, a distractor image, a 'low-probability cue' and a 'high-probability cue'. During the task's learning phase (during which ISL was expected to occur), the target image was preceded by the high-probability cue 75% of the time and by the low-probability cue 25% of the time. Throughout the learning phase, the distractor image never cued the appearance of the target.

Stimuli were presented in a Markov chain sequence, which followed the transitional probabilities set out in **Table 1**. The learning phase consisted of three blocks, each of which contained 16 targets and (on average) 40 non-targets. In each of the learning-phase blocks, 12 of the targets were preceded by the high-probability cue, while 4 were preceded by the low-probability cue. Immediately following completion of each block, participants were shown a cartoon 'progress bar' and given the opportunity for a brief rest (see **Figure 3**). It was predicted that, as the learning phase progressed, all participants' reaction times would decrease (improve) for targets preceded by the high-probability cue. However, if ISL is impaired in those with ASD, the autistic participants would be expected to show smaller improvements in response times than participants in the control group.

Table 1

Input transitional probabilities for the learning-phase stimuli sequence

Displayed image	Subsequent image			
	Distractor	Low-probability cue	High-probability cue	Target
Distractor	0	0.5	0.5	0
Low-probability cue	0.375	0	0.375	0.25
High-probability cue	0.125	0.125	0	0.75
Target	0.333	0.333	0.333	0

Note. Figures represent the probabilities of the currently displayed image's being followed by a particular subsequent image. For example, when the displayed image was the distractor, it was never followed (0) by the target image during the learning phase but was followed half of the time (0.5) by the low-probability cue and half of the time (0.5) by the high-probability cue. When the 'current image' was the target, all other images were equally likely (with a probability of 0.333) to appear next.

Figure 3

Tablet task progress screen

Note. A progress screen was shown to participants following the completion of a block (in this example, the first block in the learning phase). Participants were given the opportunity to rest briefly before continuing with the task.

A fourth 'disruption' block contained a further 12 presentations of the target image. In this block, stimuli were presented in an order that contradicted the learning phase's transitional probabilities. For example, the 'distractor' image, which never cued the appearance of the target during the learning phase, preceded 6 of the 12 disruption block targets. It was predicted that, because some degree of ISL would have taken place during the learning phase, all participants would demonstrate increased RTs throughout the disruption block. Again, if ISL is impaired in those with ASD, the increase in RTs between the end of the learning phase (for high-probability-cued targets) and the disruption block should be smaller for autistic participants than those in the TD control group.

ISL task procedure: The experimenter welcomed the child to a quiet room (within their own school) and asked them to sit at a desk. Children with autism were often accompanied by learning support assistants or other members of teaching staff. Adults who attended with the children were asked not to assist with any of the activities. After the child had confirmed that they were willing to proceed, the ISL task was administered using the following procedure.

To increase motivation during the task, participants were asked to select a picture set that most interested them from a choice of three. The options were a group of four cartoon characters, a group of four transport vehicles and a group of four animals. Within each group, the images were identical in size, resolution and luminance. The pictures within each group were also designed to be as similar in content as possible, while still being easy to differentiate. In the 'cartoon' group, all of the characters (Bart Simpson, Winnie the Pooh, a Minion and SpongeBob SquarePants) were predominantly yellow and set against a white background. In the 'transport' group (coach, boat, aeroplane and train), each picture was of a predominantly white vehicle on a sunny day. In the 'animals' group, the chicken, dog, monkey and turtle were all predominantly brown in colour and displayed against a white background (see **Figure 4**). After choosing their preferred set of images, the participant was asked to choose their favourite picture from that set. This picture became their target image throughout the following task.

Figure 4

Task stimuli from the animals group of images

Note. Each participant was asked to pick their favourite from the group of four. The chosen image became their target for the duration of the task.

During play, the participant used one finger to hold a central play button in place to activate the game (see **Figure 2**). This button had to remain pressed until the target image appeared, ensuring that the child's finger was in a standardised position before the presentation of a target. It also allowed self-pacing and helped to ensure that stimulus presentation continued only when the child was (at least physically) engaged in the game.

Once the game was activated, the picture window displayed a new image every 1500ms, with 250ms of blank screen between pictures. When the target image appeared in the picture window, the participant had to swipe across it as quickly as possible. Before data collection began, participants became familiar with the task in practice mode, during which the four images appeared in a repeating, predetermined order. As soon as the participant had swiped four consecutive targets correctly, without reacting to the other pictures in error, practice was terminated by the experimenter. The participant then began the learning phase of the ISL task, as set out above.

Throughout the task, reaction times were measured in two ways. Swipe reaction time (swipe-RT) was recorded as the conventional measure of time between target presentation and finger contact on the target. Lift-off reaction time (lift-RT) was also recorded as the time between target presentation and the participant's finger lifting off the centralised 'play' button. As discussed previously, lift-RT was monitored to potentially reduce any effect of sensory motor disturbances on ASD participants' recorded reaction times. Lift-RTs were included in later analyses only if finger lift-off was followed by a correct target swipe within 1500ms of target presentation.

After completing the ISL task, each participant was asked three questions to assess the extent to which they had developed explicit awareness of the underlying transitional probabilities. Firstly, they were asked 'Across the whole game, was there anything that helped you know when [target] was going to appear?'. If they answered yes, they were asked for more information. If their answer referred in any way to the high-probability cue appearing more frequently before the target (or the low-probability cue and distractor appearing less frequently before the target), they were scored as having developed explicit awareness. Participants were then shown printed pictures from the task and were asked 'Across the whole game, one picture came before [target] more often than the others. Which one?' (correct answer: high probability cue) and 'Across the whole game, one picture came before [target] less often than the others. Which one?' (correct answer: distractor image). Because participants were able to point to the relevant picture, no verbal responses were required.

While explicit awareness results are reported later in this chapter, it should be noted that this line of questioning was not practical for some of the youngest TD and the less verbal autistic participants. Future studies would benefit from developing more effective methods for testing explicit awareness following the ISL task.

2.2.5. Other assessments

Participants also completed standardised assessments of receptive language and non-verbal intelligence. Vocabulary was assessed using the British Picture Vocabulary Scale Third Edition (Dunn et al., 2009), a well-established receptive language test with an administration time of around 10 minutes. Participants were asked to identify the correct picture, from a choice of four, that best matched a word spoken by the experimenter. No verbal responses were required from participants during assessment. Raven's Coloured Progressive Matrices (Raven et al., 2000) was used to assess non-verbal reasoning/fluid intelligence. The task consisted of 36 items divided into three sets of 12. Each item contained a pattern or set of pictures with one part removed. Participants were asked to identify the correct image, from a choice of six, that completed the picture set. Again, administration took around 10 minutes, and no verbal responses were required.

2.3. Results

Because COVID-19 restrictions brought a swift and unexpected halt to data collection, participant numbers, particularly for the ASD group, were lower than planned. With just nine autistic participants tested, testing for between-group differences was not realistically viable. Not only were ASD participants few in number, they were also poorly age-matched to the TD control group. As such, the following analyses focus more on an evaluation of the ISL task itself, and any insights gained from the TD group data, than attempting to answer Study 1’s original research questions. Where between-group differences are referred to in the following analyses, any conclusions drawn should be viewed as both tentative and highly cautious.

2.3.1. ISL task evaluation

Task completion rate: The novel ISL task was designed specifically to allow the testing of younger and lower-functioning children with ASD. However, although the task interface was designed to be as simple as possible, a large proportion of the participants recruited from SEN schools did not engage with the task. Of the 39 autistic children recruited to the study, only 9 (23%) completed the initial task practice session successfully. All nine children went on to complete the rest of the ISL task, as well as the receptive language and non-verbal reasoning measures, without difficulty.

Once it had become apparent that many autistic participants were not able to engage in the ISL task, instead of such participants being eliminated from the study immediately, they were asked to attempt the study's two other tasks: the British Picture Vocabulary Scale (Dunn et al., 2009) and Raven's Coloured Progressive Matrices (Raven et al., 2000). This procedure was introduced to determine whether participants who did not engage in the novel ISL task were nevertheless able to complete other, more established, psychometric measures. A secondary goal was to gain a better understanding of the language and intelligence levels of participants who were (and were not) able to complete the ISL task. Again, due to COVID restrictions, this activity was cut short after the testing of just two autistic participants. For the record, one participant who was not able to start the ISL task completed both of the other measures successfully, whereas the other was unable to begin either of the additional tasks.

In the TD group, every participant (aged 4 to 11) was able to complete the ISL task successfully and all went on to complete the receptive language and non-verbal reasoning measures without issue. As a result of a technical issue, the number of reaction errors (participants swiping images other than their target image) was not recorded accurately and is therefore not reported here.

Explicit awareness: After completing the ISL task, each participant was asked three questions to assess the extent to which they had developed explicit awareness of the task's underlying transitional probabilities. Of the 36 participants who completed the task, 4 children (1 ASD and 3 TD) answered 'yes' to the first awareness question ('Across the whole game, was there anything that helped you know when [target] was going to appear?') *and* went on to identify both the high-probability cue and distractor pictures correctly. Therefore, around 11% of participants showed strong evidence of developing explicit awareness of the task's hidden structure. A further 6 children (1 ASD and 5 TD), or 17% of participants, answered 'no' to the first awareness question but nevertheless identified both the high-probability cue and distractor pictures correctly when prompted to do so. Three participants (1 ASD and 2 TD) did not appear to understand the explicit awareness questions.

2.3.2. Data reduction

The 4 participants (1 ASD and 3 TD) who showed strong evidence of developing explicit awareness of the task's transitional probabilities were excluded from the following analyses. This was because learning, for these participants, was unlikely to be entirely implicit in nature.

Broadly in line with Jones et al. (2018), and other studies that measured simple RT with a non-varying motor response (Moradi & Esmaeilzadeh, 2017; Townsend et al., 2001), participant swipe-RT responses under 300ms and over 1500ms were removed before analysis, as were lift-RT responses under 200ms and over 1000ms. Responses outside these time boundaries were judged unlikely to represent fully engaged attempts to react to the stimuli as quickly as possible. In total, 71 lift-RTs and 78 swipe-RTs (3.4% of all responses) were removed for this reason.

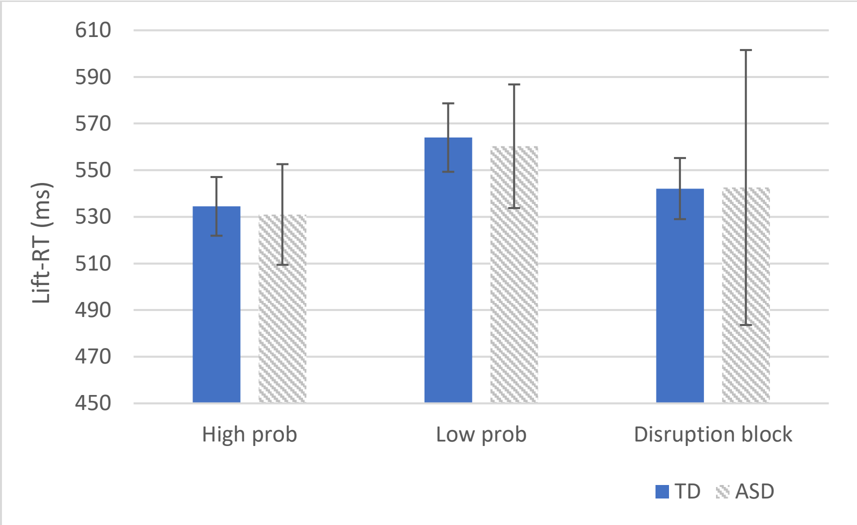
2.3.3. ISL throughout the learning phase

To establish whether the task's learning phase elicited broad evidence of ISL, participants' mean lift-RTs and mean swipe-RTs for low- and high-probability-cued targets were calculated using all responses from blocks 1 to 3. Mean lift-RTs and swipe-RTs for disruption block targets were also calculated. A 2x3 mixed design ANOVA was first conducted to examine the effect of participant type (ASD or TD) and cue condition (low-probability-cued targets, high-probability-cued targets and targets within the disruption block) on lift-RTs. Lift-RT data are displayed in **Figure 5**. The ANOVA showed a significant main effect of cue condition ($F_{(2,60)} = 5.93$, $p = .004$), indicating that the speed of initial reaction to the target picture (lift-RT) was affected by the type of cue preceding it. The ANOVA revealed no significant main effect of participant type (ASD vs

TD, $F_{(2,60)}$ = .028, p = .867) and no significant interaction between cue condition and participant type ($F_{(2,60)}$ = 1.3, p = .28).

Figure 5

Lift reaction time data, split by cue type

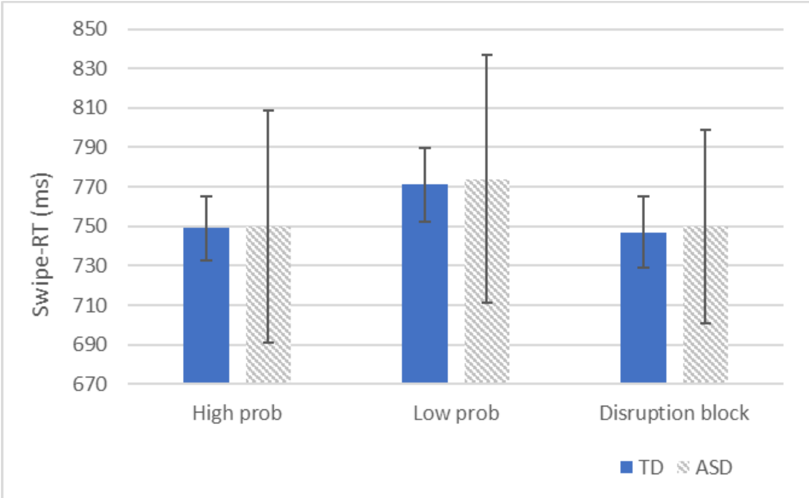


Note. Across the learning phase of the task, targets preceded by the high-probability cue were reacted to more quickly than those preceded by the low-probability cue. Error bars represent standard error of the mean (SEM).

An identical 2x3 mixed design ANOVA was conducted to examine the effect of participant type (ASD or TD) and cue condition on swipe-RT. The results again showed a significant main effect of cue condition ($F_{(2,60)}$ = 4.44, p = .016), indicating that the speed at which the target was swiped was affected by the type of cue preceding it. As in the previous analysis, there was no significant main effect of participant type ($F_{(2,60)}$ = 2.83, p = .103) and no significant interaction between cue condition and participant type ($F_{(2,60)}$ = 1.94, p = .174). However, as stated previously, because participants in the ASD group were both few in number and poorly age-matched to the control group, any between-group comparisons should be treated with extreme caution. Swipe-RT data are displayed in **Figure 6**.

Figure 6

Swipe reaction time data, split by cue type



Note. Targets preceded by the high-probability cue were swiped more quickly than those preceded by the low-probability cue across the learning phase of the task. Error bars represent SEM.

Follow-up paired-samples t-tests were conducted, using combined data from both participant groups, to determine which cue conditions were associated with the significant differences in RT. Reaction time data are summarised in **Table 2**. As would be expected if implicit learning had taken place, a significant lift-RT difference was found between low-probability-cued targets (M= 560ms, SD = 71.5) and high-probability-cued targets (M = 531ms, SD = 61.4), with targets preceded by the high-probability cue producing the lower (faster) reaction times ($t_{(31)}$= 2.92, p = .006). The same result was found for swipe-RTs ($t_{(31)}$ = 2.33, p = .026). The mean RT difference between low-probability and high-probability-cued targets was greater for lift-RTs (29.3ms) than for swipe-RTs (23.7ms). Also, as indicated by smaller relative standard deviations for all target types (see **Table 2**), RT variance was comparatively lower for 'lifts' than 'swipes'. This observation is consistent with the proposition that recording lift-RTs may help reduce the influence of participants' sensorimotor differences during RT-based tasks.

Table 2

Mean reaction time data from the novel ISL task

	Low probability-cued targets	High probability-cued targets	Disruption block targets
Lift reaction time (ms)	560 (SD = 71.5, RSD = 12.77)	531 (SD = 61.4, RSD = 11.56)	543 (SD = 65.7, RSD = 12.1)
Swipe reaction time (ms)	774 (SD = 121.8, RSD 15.74)	750 (SD = 107.5, RSD = 14.33)	750 (SD = 103.8, RSD = 13.84)

Note. Relative standard deviations (RSD) are the standard deviations, expressed as a percentage of the mean (RSD = SD x 100 / mean RT).

Because lift-RT appeared to be the more sensitive measure of reaction speed in the current study, the remainder of this section reports results only in terms of lift-RTs. This step was taken for the sake of brevity and clarity. Participants' mean lift- and swipe-RTs were highly correlated (r = 0.86) and produced similar findings in each analysis.

2.3.4. Disruption block

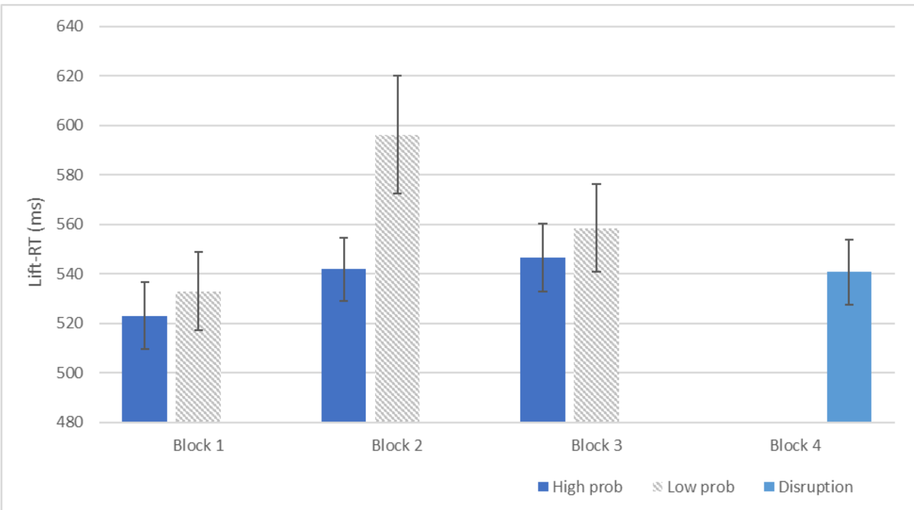
Following the three learning-phase blocks, a final 'disruption block' presented stimuli in an order that contradicted the previously learned transitional probabilities. TD participants were predicted to react more slowly to targets in the disruption block than to high probability-cued targets in block 3 (where ISL was expected to have optimised reaction speed). Contrary to predictions, a paired-samples t-test found no significant lift-RT difference between targets preceded by the high-probability cue in block 3 (M = 547ms, SD = 67.8) and targets in the disruption block (M = 541ms, SD = 64.2, $t_{(23)} = 0.87$, p = .4). Therefore, while RTs were predicted to slow when the learned transitional probabilities were disrupted, no such effect was detected by the novel ISL task.

2.3.5. Reaction time trends

As can be seen in **Figures 7** and **8**, another unusual observation from the ISL task data was that RTs (even for the high-probability-cued targets) appeared not to reduce (get faster) in the predicted way at all. For most SRT tasks, TD participants would be expected to improve reaction speed (reduce RT) as implicit learning took place throughout the learning phase. However, in the current study, lift-RTs tended to slow as the task progressed. The same was true for swipe-RTs. As confirmed by the earlier t-tests, a significant RT difference emerged between low- and high-probability-cued targets within the learning phase. However, this effect was not produced by high-probability cues eliciting greater RT reductions than low-probability cues as the task progressed. Mean high-probability-cued RTs increased steadily from blocks 1 to 3, whereas mean low-probability-cued RTs were longest (slowest) during block 2.

Figure 7

Mean lift-RTs by block

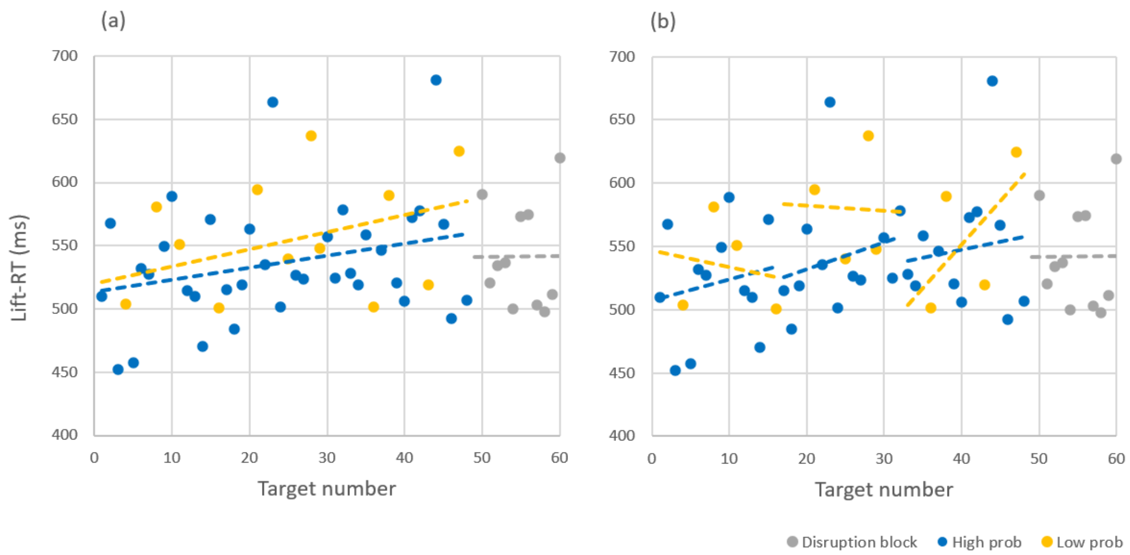


Note. Data from TD participants only. Contrary to predictions, reactions to the target did not become faster throughout the learning phase of the task (blocks 1 to 3). Also, disruption of the learned transitional probabilities (block 4) did not cause the expected increase (slowing) of RTs. Error bars show SEM.

High-probability-cued targets: To investigate this trend further, lift-RT data from all high-probability-cued targets (36 responses per participant from blocks 1 to 3) were fitted to multilevel models. The data were first fitted to a random intercept/fixed slope model, which allowed only the regression line intercepts to vary between individual participants. Lift-RTs were predicted by 'target number' (the total number of target images presented thus far), allowing an analysis of RT change as the task progressed. This type of model allowed analysis of repeated RT measures without violating the 'independence of residuals' assumption required of linear regressions. Results indicated that target number was associated with a significant increase in lift-RT. On average, lift-RT increased (slowed) by 0.86ms for each subsequent target ($t_{(807)} = 3.46$, $p < .001$), from a mean initial lift-RT of 516ms (SD = 59.25).

Figure 8

Mean lift-RTs from TD participants throughout the novel ISL task



Note. Learning blocks 1 to 3 each contained 16 targets (12 high-probability-cued and 4 low-probability-cued). The disruption block contained 12 targets. Participants were given the opportunity for a brief rest between blocks. Chart (a) shows general linear trends throughout the task. Chart (b) is a plot of the same data, but with separate trend lines for each block within the task.

The data were then fitted to a random intercept/random slope model, which allowed regression line intercepts *and* slopes to vary between participants. Using maximum-likelihood estimation, the two models were compared. The 'likelihood ratio' test (based on the change in the -2 log-likelihood statistic from the first to the second model) and its associated significance (likelihood ratio = 0.71, p = .7) indicated that the addition of random slopes to the first model did not significantly improve data fit. Therefore, multilevel analysis suggested that participants' reaction speeds (lift-RT to high-probability-cued targets) slowed to a similar extent throughout the task, after allowing for individual differences in initial RT.

Low-probability-cued targets: The same method of analysis was applied to lift-RT data from all low-probability-cued targets (12 responses per participant across blocks 1 to 3). Lift-RTs were again predicted by 'target number' to allow analysis of RT change as the task progressed. The data were first fitted to a random intercept/fixed slope model, which allowed just the regression line intercepts to vary between participants. Results again indicated that reaction speed slowed significantly throughout the task, with lift-RTs increasing by an average of 0.96ms for each subsequent target ($t_{(244)} = 2.01$, p = .046) from a mean initial RT of 534ms (SD = 64.58). The data were then fitted to a random intercept/random slope model, which allowed regression line intercepts *and* slopes to vary between participants. As with the high-probability-cued targets, the addition of random slopes did not improve data fit (likelihood ratio = 0.89, p = .64), indicating that participants' low-probability-cued RTs slowed to a similar extent throughout the task, after allowing for individual differences in initial reaction speed.

2.3.6. Language development

Because several aspects of language development have been linked to implicit learning, a positive correlation between receptive vocabulary and ISL task performance was predicted. A multiple linear regression was conducted to examine the relationship between children's vocabulary (British Picture Vocabulary Scale raw score) and their ISL task performance, age (in months) and fluid intelligence (Raven's Coloured Progressive Matrices raw score). Each participant's ISL task performance was quantified as the mean difference in lift-RT (in milliseconds) between low- and high-probability-cued targets across the learning phase of the task (blocks 1 to 3). Larger lift-RT difference figures here indicated better learning of the underlying transitional probabilities. This ISL measure was chosen for two reasons. Firstly, inspection of the data (see **Figures 7** and **8**) suggested that the greatest difference between high- and low-probability-cued targets may not have occurred at the end of the learning phase (as would be expected in most ISL tasks). Secondly, because fewer participants were tested than planned, and because each participant reacted to just 4 low-probability-cued targets per block, analysing all responses from blocks 1 to 3 optimised use of the limited data available. As before, autistic participants' data were excluded from this analysis as were the data from the 3 TD participants who may have gained explicit awareness of the task's underlying structure. These exclusions left data from 24 TD children.

The regression model was a good fit to the data ($F_{(3,20)} = 23.18$, $p < 0.001$) with an R^2 of 0.78. TD participants' fluid intelligence ($\beta = 1.36$, $p = .009$) and age ($\beta = 0.5$, $p = .004$) significantly predicted vocabulary score. However, ISL task performance did not predict receptive vocabulary score ($\beta = -.003$, $p = .962$). Because COVID restrictions prevented the collection of the autism screening/social impairment questionnaires, the relationship between ISL task performance and children's social development could not be examined.

2.4. Discussion

Insufficient data were collected to answer Study 1's original research questions. The current study was therefore effectively reduced to a feasibility trial of a novel task designed to assess ISL in younger and lower-functioning autistic children. Based on the limited data available, this novel ISL task could be summarised as 'partially successful'. The novel task *did* appear capable of detecting the effects of ISL. Over the course of the task's learning phase, high-probability cue images elicited faster reactions to the target than did low-probability cue images. Such a finding indicates that participants acquired knowledge of the statistical relationships underlying the presentation of stimuli. The task was also largely successful in keeping this learning implicit in nature. Only 11% of participants demonstrated clear evidence of having gained explicit awareness of the predictive value of the high-probability cue. Because these participants were excluded from the above analysis, ISL would seem the most likely mechanism to account for the observed RT difference between cue types. While the novel task did appear to quantify ISL, a simple measure of task performance was not predictive of children's receptive vocabulary scores. Because ISL is known to be important for many aspects of language acquisition, this apparent lack of association was somewhat surprising. However, it should be remembered that data were available from just 24 TD children with a relatively wide age-range (4-11 years). It would therefore be unwise to draw any firm conclusions from this finding.

2.4.1. Task accessibility

While successful in detecting the effects of ISL, there are aspects of the task that clearly require further development. Of primary importance are the accessibility and suitability of the task to its target participants: young, lower-functioning autistic children. After recruiting autistic participants through SEN schools in the UK, only 23% (9 of 39) demonstrated that they understood the task and were engaged during the pre-task practice session. All 9 children went on to complete the remainder of the task without difficulty. Similarly to Jones et al. (2018), the task interface and instructions were kept as simple as possible. Engagement was also encouraged by allowing children to choose their own preferred set of images and targets. These measures succeeded in making the task accessible to 4-year-old TD children but did not ensure engagement for a large proportion of the autistic participants.

On reflection, a significant number of the autistic children who did not engage with the task appeared to lack the sustained focus or inclination to attend to the tablet computer, the task or the experimenter. However, reasons for task non-completion were not recorded systematically at the time of testing. In the UK, SEN schools often categorise pupils as having moderate/mild learning difficulties (MLD), severe learning difficulties (SLD) or profound and multiple learning disabilities (PMLD). Again, this information on level of impairment was not collected systematically at the time of testing, as each child's level of social communication functioning was originally due to be assessed for the study by both parents and teachers. However, some of the schools voluntarily provided 'learning difficulty' category information when compiling lists of participants. On a casual observational basis, children with MLD rarely had difficulty in engaging with (and completing) the novel ISL task. Children with SLD, however, seemed significantly less likely to pass the practice phase of the task. As a consequence of the study's exclusion criteria, few (if any) children with PMLD were selected as participants.

Therefore, the novel task appeared well-suited for use with autistic children with MLD, but less so for those with lower levels of functioning. These observations are not supported by quantitative empirical data but are included here for the benefit of any future researcher who might attempt to test lower-functioning autistic children in a similar way. Jones et al. (2018) reported that just 1 of 56 autistic participants were excluded from their study after recording no responses to the target image. The paper made no mention of any children being excluded after failing to master their pre-task practice trials, a surprising omission given the high proportion of 'drop-outs' in the current study. It would have been useful to compare impairment severity across the two studies' sets of autistic participants. However, because this information was not collected for the current study because of COVID-related school closures (or included in the paper by Jones et al.), any such comparison is impossible.

While it is important to identify problems with the novel task's accessibility, it remains far from apparent how this type of task could be simplified further, or generally made more suitable for its intended participants. Any such task that requires active participation, sustained attention (even for relatively brief periods) and the following of instructions (however simple) may prove equally inaccessible to young autistic participants with severe learning difficulties. One obvious solution would be to only recruit ASD participants with MLD to studies such as this. However, such a restriction would defeat the current study's main purpose, which was to investigate ISL in lower-functioning autistic children.

A potentially fruitful alternative approach could be to adapt ISL tasks that require no active involvement from participants. For example, Saffran and colleagues (1996), as described in Chapter 1, quantified ISL in 8-month-old infants using the dishabituation effect. Babies were first played a continuous audio stream consisting of three-syllable nonsense words. When the infants were exposed to further audible syllable strings, they displayed a novelty preference, listening longer to new syllable strings than ones they had learned implicitly from the initial speech stream. Paradigms such as this have not yet been adapted to assess behavioural indications of ISL in low-functioning autistic children. While it would remain important to gain the child's assent for any such task, this could be a worthwhile area for further investigation. Atypical patterns of neural activation have been detected when autistic participants were exposed to passive ISL tasks (Jeste et al., 2015; Scott-Van Zeeland et al., 2010). It therefore seems possible that similar tasks could elicit behavioural differences too.

Another approach to engaging young autistic participants could be to integrate testing with child-friendly games. Hopkins et al. (2004) devised a probabilistic classification task in which participants were shown a Mr. Potato Head toy figure and were asked to 'guess' whether he wanted chocolate or vanilla ice cream. Correct answers were rewarded, and feedback given for incorrect answers. Unknown to participants, various cues (such as the presence of a hat, glasses and moustache) were each associated probabilistically with the character's ice cream preference. For example, the hat was associated with 'vanilla' on 80% of trials. Correct answers above the level of chance indicated that participants had learned the statistical cues underlying the stimuli. Adapting toy-based tasks, such as this, could conceivably facilitate data collection with target participants. Indeed, McKinney et al. (2021) suggested that integrating play with testing was an effective tactic when collecting data with non-verbal and minimally verbal autistic participants. From their own experiences, McKinney and colleagues found that moving seamlessly between play and testing, while interacting physically with participants, often optimised participant engagement and the chance of collecting high-quality data (McKinney et al., 2021). Such an approach could be adopted to assess ISL in young, lower-functioning autistic children.

2.4.2. Fatigue and reactive inhibition

In most 'standard' SRT tasks, RTs are longest (slowest) at the beginning of the task. As the task progresses, participants typically record faster RTs as they become accustomed to the task requirements and map the multiple on-screen stimuli to their specific response keys. This improvement in reaction speed occurs independently of any sequence-specific statistical learning. Because of this effect, random stimuli are often inserted into SRT tasks (between sequenced stimuli) that track a baseline RT as the task continues. ISL is usually quantified by comparing participants' baseline RT to their speed of reaction to stimuli that form part of the hidden sequence. When sequence-specific RTs become significantly faster than baseline RTs, this RT difference is taken as evidence that the participant has acquired implicit knowledge of the task's underlying structure. An alternative method for assessing ISL in a SRT task is to include a block of random stimuli after the learning phase of the task. Because this disrupts the sequence that participants had learned implicitly, increased (slower) RTs during this ‘disruption block’ also signify that ISL has occurred. The current task employed both methods to measure ISL. The task’s equivalent of baseline RTs were established by monitoring responses to the target following the low-probability cue.[7] A disruption block was also inserted at the end of the task, in which the order of stimuli no longer obeyed the transitional probabilities established previously. However, RT data from the current study deviated from the above expectations in two important ways.

Firstly, there was no significant RT difference between targets in the disruption block and those preceded by the high-probability cue during the learning phase of the task. This null effect is somewhat difficult to explain, given that ISL had taken place during the learning phase. However, the study tested fewer participants than intended and only 12 targets were included in the novel task’s disruption block. Because the expected RT difference would have been small, it is possible that the current study simply did not collect sufficient data to detect a significant ‘disruption block effect’. Another potentially contributing factor is that, unlike in other SRT tasks, the order of stimuli in the current task was not guided by a deterministic sequence or regular non-adjacent dependencies. Because there was no recurring (albeit hidden) sequence to violate, RTs may have been affected to a lesser extent by the inclusion of a disruption block.

There was a second unusual observation from the current study’s data. While high-probability cues *did* elicit significantly faster RTs than low-probability cues during the learning phase, high-probability cued RTs were actually lowest (fastest) in block 1 and then became slower with each successive block. The low-probability cue also elicited its fastest RTs in block 1, with the slowest mean RTs occurring in block 2. One potential explanation for this finding is that task requirements in the current study were simplified to such a great extent that participants’ reaction speeds were optimised very early in the task. Unlike most SRT tasks, the current task required participants to react to a single

[7] In most SRT tasks, baseline RTs are measured using stimuli that do not form part of the learning sequence. As there was no recurring sequence in the current study, baseline RTs were instead established using responses to the target preceded by the low probability cue (which was poor at predicting the subsequent appearance of the target). As such, it could be argued that the current study did not establish ‘true’ baseline RTs. The current study was, however, able to monitor the ongoing RT difference between instances when the target was statistically likely to appear (i.e., following the high probability cue) and when it was not (i.e., following the low probability cue).

target with a simple, invariant motor response (a swipe across the large target image, which always appeared at the same location on screen). It has long been known that increasing the complexity of a required response results in a corresponding increase in RT (Maslovat et al., 2019). It is also well established that when reactions require a complex (rather than simple) movement, more practice is required before participants achieve their optimal reaction speed. For example, Norrie (1967) administered 50 RT trials to two groups of participants; one group was asked to respond with a complex arm movement, the other with a simple arm movement. The 'complex movement' group continued to improve RT throughout the experiment, whereas RT improvements had levelled off for the 'simple movement' group within 20 trials. It is possible, therefore, that participants in the current study adapted quickly to the task demands, achieving their fastest RTs within the brief practice session or within the early stages of block 1. Fatigue effects, often referred to in the literature as 'reactive inhibition', would then presumably cause a slowing of reactions throughout the remainder of the task.

Reactive inhibition was a term first coined by Clark Hull in the 1940s. It was initially proposed as a behaviourist mechanism of 'drive reduction' (Hull, C. L., 1943) but has since been redefined as the accumulative deterioration in performance whenever the same task is repeated numerous times. Reactive inhibition is characterised by a progressive decline in decision accuracy and motor execution over time (Török et al., 2017) and may therefore be particularly relevant to SRT tasks. When participants perform RT tasks arranged in blocks, their reactions become slower throughout each block, with performance (at least partially) restored after a brief rest between blocks (Brawn et al., 2010; Nemeth et al., 2013; Rickard et al., 2008). A performance measure such as RT is therefore driven in opposing directions by ISL and reactive inhibition, with ISL working to improve reaction speed over time while reactive inhibition does the reverse. It is therefore important to control for reactive inhibition when analysing the results of RT studies. Török et al. (2017), for example, found that the magnitude of the 'reactive inhibition effect' during SRT tasks can be larger than that of ISL. As a consequence, Török and colleagues were able to identify a significantly larger effect of ISL once individual differences in reactive inhibition had been controlled for.

In the current study, reactive inhibition may help explain the absence of a significant 'disruption block effect'. The disruption block was shorter than the blocks in the learning phase (37 total stimuli/12 targets in the disruption block, compared with 54 to 57 stimuli/16 targets in blocks 1 to 3). The cumulative deterioration effect on RTs may, therefore, have been smaller for the disruption block than for the longer learning blocks, resulting in faster mean RTs. An important requirement for future studies of this kind is, therefore, that the disruption block should be equal in length to each learning block (especially the final learning block), if the difference in mean RTs will be used to quantify ISL.

Reactive inhibition may also help to explain the general tendency for RTs to slow throughout the learning phase of the task. As described previously, if participants' RTs were optimised early on because of the task's simplicity, RTs were almost guaranteed to lengthen from that point onwards as a result of reactive inhibition. While RTs did tend to grow steadily longer, a significant RT difference still emerged between high-probability and low-probability cued targets. Viewed from the context of reactive inhibition, this outcome would seem to make sense. Successful ISL would have driven high-probability-cued RTs *down* by a small amount during the learning phase. Conversely, reactive inhibition would have simultaneously driven both high- *and* low-probability cued RTs *up* by a larger amount. This combination would explain the general lengthening of RTs observed throughout the learning phase as well as how a RT difference could still emerge (between cue types) amidst this general trend.

2.5. Summary, conclusions and a new direction

Study 1 set out to investigate ISL in young, lower-functioning autistic children, a group largely overlooked by previous research. A novel ISL task was developed with this goal in mind, based on the work of Jones et al. (2018). The new task introduced a stimulus sequence based on transitional probabilities to boost ecological validity, while lift-RTs (in addition to swipe-RTs) were recorded to reduce the potential influence of ASD-related motor deficiencies.

While the novel ISL task proved suitable for use with some children in SEN schools, around three quarters of autistic participants were not able to complete the testing process. The difficulty of designing a truly accessible task, combined with the unfortunate onset of the coronavirus pandemic, meant that insufficient data were collected to address the study's initial research questions. Analysis of the limited data that were collected (predominantly from TD children) showed that the task successfully detected the effects of ISL. High-probability cues elicited faster responses than low-probability cues from participants who reported no awareness of the task's underlying structure. However, ISL task performance was not significantly correlated with the study's measure of language development (receptive vocabulary). The novel task used low-probability-cued trials throughout the learning phase to monitor the effects of reactive inhibition. A preliminary analysis of task data revealed that reactive inhibition may have exerted a large influence on the study's recorded RTs. This finding highlighted how important it may be to factor fatigue effects into the design of any similar ISL task.

Unfortunately, the coronavirus pandemic not only hobbled the longitudinal aspect of the current study but remained an ongoing obstacle for the larger research programme planned for this thesis. While schools re-opened several months after Study 1 was discontinued, many children's learning remained behind schedule following their extended period of home education. Because of this disruption, and the resulting increased workload for teachers, schools that had agreed previously to participate in research were no longer in a position to do so. Combined with the difficulties experienced in testing young, lower-functioning autistic participants, these situational practicalities prompted a shift away from investigating ISL in children.

The remaining studies in this thesis continue to investigate implicit learning and its relationship to autism. However, these studies focus on implicit *social* learning and its relationship to dimensional autistic traits in adults. Before studies 2, 3, 4 and 5 are presented, it is necessary to revise the research questions and discuss the evidence that guided their formation. What follows is, therefore, a second 'introductory' chapter that lays the foundations for a series of necessarily reformulated studies.

Chapter 3. Introduction II: Return of the introduction

Social distancing measures put in place during the coronavirus pandemic made it impracticable to continue conducting research with children in schools. The situation necessitated a revision of some of the research topics set out previously in this thesis. New studies were devised to investigate implicit social learning, and its relationship to autistic traits, that remained accessible through work with adult participants (initially via online data collection). This supplementary introductory chapter sets out the rationale for these new studies and summarises the evidence that led to their design.

3.1. Measurement of dimensional autistic traits

As described in Chapter 1, autism is diagnosed using behavioural indicators of social communication difficulties, restricted interests and repetitive behaviours (American Psychiatric Association, 2013). Diagnoses are invariably categorical, with clinicians (or multidisciplinary autism teams in the UK) assessing behavioural evidence of autistic traits (and the extent to which they impair functioning in 'everyday life') before concluding that a person warrants an ASD diagnosis, or that they do not.

In contrast to this dichotomous process, it is now generally accepted that autistic traits are dimensional, existing to varying extents in individuals throughout the general population (Baron-Cohen et al., 2001b; Brondino et al., 2018; Constantino, John N. & Todd, 2003; Hoekstra et al., 2007; Ruzich et al., 2015). People low in dimensional autistic traits are unlikely to display many autism-like behaviours. However, higher (but still subclinical) levels of autistic traits might manifest, for example, as 'eccentric' social behaviour, unconventional patterns of speech or an unusual reluctance to break from routine. The expression of higher (but still subclinical) autistic-like traits was first observed in members of autistic individuals' families and has been referred to as the 'broader autism phenotype' (Bolton et al., 1994). Qualitatively similar to ASD, the broader autism phenotype is associated with reduced communication skills, 'aloofness' and behavioural rigidity (Wainer et al., 2011) as well as impairments in social awareness and functioning (Sasson et al., 2013). Higher levels of subclinical autistic traits at 15 months have been shown to predict behavioural difficulties and language delays years later (Möricke et al., 2010), indicating that the presence of such traits may have a nontrivial influence on later development.[8] Whether autistic symptomatology follows a truly continuous distribution in sub-clinical samples remains a subject of debate (Abu-Akel et al., 2019; Chown & Leatherland, 2021; Happé & Frith, 2021). However, many researchers now agree that it is often useful to conceptualise autistic traits as dimensional, with autistic individuals residing within the tail of a wider bell-shaped distribution (English et al., 2021).

In Study 1, the original intention was to compare the ISL abilities of young autistic children to those of children in a control group. A secondary goal was to investigate whether group differences in ISL ability relate to group differences in vocabulary and social skill acquisition. Several of the remaining studies in this thesis, complementarily, focus on TD participants' dimensional autistic traits, to investigate how *they* might relate to implicit learning and other abilities.

Many studies have investigated dimensional autism, often turning to the Autism Spectrum Quotient (AQ, Baron-Cohen et al., 2001b) to quantify autistic traits in non-autistic participants. The AQ is a self-report questionnaire designed for use with adults of normal to high intelligence. The measure's 50 items are divided equally into 5 subscales designed to quantify strengths and weaknesses in social skill, attention switching, communication, attention to detail and imagination (Baron-Cohen et al., 2001b). Studies employing the AQ have shown that higher trait autism, after controlling for sex differences, significantly predicts reduced empathy in the general population (Shah et al., 2019) and that higher AQ scores are associated with reduced spontaneous reciprocation of direct gaze (Chen, F. S. & Yoon, 2011).

Importantly, Hudson and colleagues (2012) associated high AQ scores with reduced implicit learning of social information. Participants repeatedly observed two identities whose gaze direction and facial expressions consistently conveyed either a pro- or an anti-social disposition. Subsequently, participants completed a gaze-cueing task in which

[8] While higher levels of subclinical autistic traits were predictive of adverse outcomes in Möricke et al.'s child sample, they were not predictive of later ASD diagnoses.

peripheral targets were non-predictively cued by the two identities. Typically, people react faster when gaze cues and target location are congruent (the gaze-cueing effect), a phenomenon moderated by social factors related to the identity (Dalmaso et al., 2020). Hudson et al. found that the pro-social identity produced a significantly larger gaze-cueing effect (than the anti-social identity) *only* in the low-AQ group. This finding prompted the conclusion that higher-AQ participants had not implicitly learned the identities' dispositions from the earlier facial cues, negating any influence of social factors on the subsequent gaze-cueing task (Hudson et al., 2012). This study and its findings are discussed in greater detail in Chapter 4.

In the remaining studies in this thesis, dimensional autistic traits were assessed using an abridged version of the AQ, the Autism Spectrum Quotient-Short form (AQ-S, Hoekstra et al., 2011). The AQ-S contains 28 statements (for example, 'I find it easy to work out what someone is thinking or feeling just by looking at their face' and 'New situations make me anxious') which participants respond to using a 4-point Likert-type scale, with options ranging from 'definitely agree' to 'definitely disagree'. Items are scored (or in many cases reverse scored) so that 'definite agreement' with an autistic trait statement garners 4 points, while 'definite disagreement' receives 1 point. Item scores can then be summed, resulting in a minimum score of 28 (indicating no autistic-like traits) and a maximum score of 112 (indicating full endorsement of all autistic trait statements).

When validating the AQ-S using TD participants, Hoekstra et al. found very high correlations between AQ and AQ-S scores ($r = .93$ to $.95$). Confirmatory factor analysis revealed that the AQ-S had a simpler structure than the AQ, with the AQ-S's 28 items loading onto just two higher-order factors: 'broad difficulties in social functioning' (23 items) and 'fascination for numbers/patterns' (5 items). As will be discussed below, the remaining studies in this thesis investigated implicit learning in the social domain. For reasons presented throughout the remainder of this chapter, it might be predicted that reduced implicit social learning would relate particularly strongly to 'broad difficulties in social functioning'. This hypothesis is tested in Study 3 (see section 5.3.4). Kuenssberg et al. (2014) later corroborated the AQ-S's two-factor structure after collecting data from autistic participants, while Murray et al. (2014) provided evidence that the AQ-S measures the same underlying traits in both TD and autistic individuals. Because both the AQ and AQ-S are generally well-supported by evidence, the AQ-S was selected as the measure of choice primarily due to its shorter administration time. Limiting the duration of testing was of particular importance in studies 2, 3 and 4, for which data were collected online. To maintain consistency, the AQ-S was retained as the autistic trait measure for Study 5 (for which data were collected in person).

3.2. Implicit learning in the social domain

As described in the first introductory chapter, a substantial body of research indicates that older children and adults with high-functioning autism (HFA) perform similarly to controls on a wide range of ISL measures (Brown et al., 2010; Foti et al., 2015; Izadi-Najafabadi et al., 2015; Kourkoulou et al., 2012; Mayo & Eigsti, 2012; Nemeth et al., 2010; Obeid et al., 2016). Autistic individuals, however, have also shown signs of employing *explicit* learning strategies during tasks designed to assess implicit learning (Klinger et al., 2007; Zwart et al., 2017). Because explicit learning (unlike ISL) is highly correlated with intelligence (Gebauer & Mackintosh, 2007; Reber, A. S. et al., 1991), and the autistic participants in the studies cited above had average to high intelligence, participants may have been able to employ explicit learning strategies with a significant degree of success. Therefore, while autistic and TD participants have performed similarly on numerous ISL tasks, the learning processes underlying those performances may have differed.

There is, however, another way of interpreting autistic and TD participants' similar performance on ISL tasks. The tasks most commonly employed to investigate implicit learning (for example, contextual cueing, serial reaction time, artificial grammar learning and probabilistic classification tasks) are all essentially non-social in nature. Conversely, it could be argued that it is the *social* difficulties common in autism that are the condition's most salient feature. When taken at face value, evidence suggests that people with HFA *are* fully capable of learning sequences and artificial grammars implicitly. However, even if this is true, an autism-related deficit might still impede implicit learning specifically within the social domain.

Three proposed mechanisms, set out in the following sections, provide theoretical support for this suggestion. Firstly, attentional factors (associated with higher autistic traits) may reduce opportunities for implicit social learning. Alternatively, or perhaps additionally, cognitive factors related to autistic traits may limit the availability of socially relevant information that would otherwise enhance implicit leaning. Two such mechanisms ('disrupted processing of affect' and 'reduced implicit mentalising') are discussed here, though others may exist. Following this chapter, this thesis presents a series of studies that tested whether autistic traits relate to a reduced ability to learn social information implicitly. An important additional goal was to investigate whether any effects found were better explained by attentional factors or by a more fundamental impairment in social cognition related to autism.

3.2.1. Reduced attention to social stimuli

As described in Chapter 1, Chevallier et al. (2012) proposed that children with autism find social stimuli inherently less rewarding than do TD children. As a consequence of their altered reward processing, autistic children are thought to prioritise attention towards social aspects of their environment to a lesser extent than their TD peers. Children with ASD may therefore miss valuable social and language input that could otherwise facilitate implicit learning. This 'self-administered' barrier to learning opportunities could not only promote the social communication difficulties that are a hallmark of ASD but may also increase autistic children's risk of developing an intellectual disability (Vivanti et al., 2013). See section 1.5.4 for a more detailed summary of the evidence.

Research largely supports the notion that both altered reward processing and reduced social attention persist into adulthood for people with ASD. Several studies have demonstrated that, in adults, both ASD and subclinical autistic traits are associated with atypical reward processing (Cox et al., 2015; Dichter et al., 2012; Greene, R. K. et al., 2020). For example, in one MRI study, the ASD group (but not TD controls) demonstrated reduced activation in the left dorsal striatum when they received social, but not monetary, rewards (Delmonte et al., 2012). The left dorsal striatum is an area of the brain known to be important for integrating reward processes with wider executive functions and action control. The authors proposed that reduced activity in this area, as seen in the autistic participants in their study, may lessen the extent to which social reinforcement influences subsequent behaviour (Delmonte et al., 2012).

Hedger and colleagues' (2020) meta-analysis also found robust evidence for reduced social orienting in people with ASD, particularly where task stimuli featured social exchanges between people. While the studies that met Hedger et al.'s inclusion criteria skewed towards child and adolescent samples, diminished social attention appeared stable across all age ranges. Another recent study also demonstrated subtle social attentional differences associated with autistic adults. Kaliukhovich et al. (2020) conducted an eye-tracking study in which participants viewed short video clips of two actors engaged in a shared activity. Compared to TD controls, autistic adults spent less time looking at the actors' face/head regions in certain contexts, particularly when the actors were engaging each other with mutual gaze. It seems plausible, therefore, that atypical allocation of attention may limit social implicit learning opportunities for adults with autism.

In particular, diminished attention to others' eyes has long been considered a hallmark of ASD. This behaviour is one of the earliest observable characteristics of the condition (Jones, W. & Klin, 2013) and often features in both child and adult autism screening instruments (Lord et al., 2000; Robins et al., 2001). Recent evidence suggests that, in line with the Social Motivation Theory (Chevallier et al., 2012), young autistic children tend to be 'gaze indifferent', passively perceiving others' eyes as less rewarding and therefore less worthy of sustained attention (Moriuchi et al., 2017). However, some older autistic children and adults report, or demonstrate evidence of, 'gaze aversion', a more active avoidance of eye contact to prevent feelings of threat and negatively valenced overstimulation (Corden et al., 2008; Hadjikhani et al., 2017; Joseph et al., 2008; Tanaka & Sung, 2016; Tottenham et al., 2014; Trevisan et al., 2017).

Regardless of the reason for the behaviour, autistic individuals of all ages tend to spend less time looking at others' eyes than those without autism. However, during social interactions, the eye region provides important information about people's mental states. The Reading the Mind in the Eyes Test (RMET), for example, has shown that TD participants can accurately infer people's emotions even from static, cropped, black and white photographs of their eyes (Baron-Cohen et al., 2001a). A meta-analysis of 18 RMET-based studies found that, compared to controls, autistic individuals consistently underperformed on this task, though the factors mediating this finding were less clear (Peñuelas-Calvo et al., 2019).[9]

Nevertheless, eye monitoring is known to aid the rapid learning of 'mental state' information, and an autism-related propensity exists to divert attention from the eyes. It seems possible, therefore, that reduced attention to others' eyes might cause autistic individuals to miss informative social disposition cues that would otherwise aid implicit learning. However, to date, this possibility has not been tested directly using a behavioural measure (see section 1.5.4).

A series of studies, based on the paradigm developed by Hudson et al. (2012), was therefore designed to investigate the relationship between dimensional autistic traits in adults and the implicit learning of characters' social dispositions from facial cues. Importantly, one study (Study 2) quantified social ISL in participants who were specifically required, by a secondary task, to monitor characters' eye regions (which provided particularly salient social cues in the studies' stimuli). A later study (Study 4) measured social ISL in participants who were free to allocate their attention to any area of the face. When combined, the studies were therefore able to test whether the 'attention to eyes' manipulation affected social ISL in higher autistic trait participants to a greater extent than those lower in autistic traits. Such a finding would implicate attentional factors, linked to autistic traits, in the implicit learning of others' mental states.

3.2.2. Disrupted processing of affect

As described in section 1.4, implicit automatic processes are thought to enable people to make seemingly effortless sense of rapidly changing social environments. As such, implicit learning has been proposed as the mechanism that underpins social intuition (Lieberman, 2000), though little direct evidence exists to support this claim. For implicit learning to be effective in dynamic social situations, Macinska (2019, p. 25) argued that it must rely "*inherently on associated emotions and affective valences, with abstract concepts such as disposition, attitude and intention being an intrinsic part of what is*

[9] Different aspects of intelligence may underlie RMET performance in TD and autistic individuals (Peñuelas-Calvo et al., 2019). Autism-related difficulties in emotion recognition may also contribute to RMET underperformance (Oakley et al., 2016, and see the following section).

learned". In other words, implicit learning must enable people to discern others' mental states, intentions and attitudes (not just sequences in their actions) if it is to help guide behaviour during real life social exchanges.

However, a large proportion of autistic individuals may experience fundamental difficulties in the processing of emotions. Alexithymia is a subclinical personality trait characterised by impaired emotional awareness (Sifneos, 1973). People with alexithymia often have difficulty identifying or understanding their own feelings, as well as difficulty recognising emotions in others. The resulting poor understanding of emotional social cues (such as facial expressions and tone of voice) often impedes social interaction (Poquérusse et al., 2018). It is no great surprise that alexithymic traits are often present in people with autism. A recent meta-analysis suggested that around 50% of those with ASD surpassed the Toronto Alexithymia Scale's (Bagby et al., 1994) 'diagnostic' cut-off score, compared to less than 5% in the general population (Kinnaird et al., 2019).

While a full discussion of the relationship between alexithymia and autism is beyond the scope of this chapter, research suggests that the two conditions may be related, but distinct (Cuve et al., 2021; Oakley et al., 2016). A similar neurological aetiology is a certainly a possibility. Both alexithymia and autism are associated with atypical connectivity around the amygdala and insula; brain regions involved in emotion processing (Gibbard et al., 2018; Kana et al., 2014; van der Velde et al., 2013). Interestingly, individuals with alexithymia demonstrate notably reduced activity within the neural structures involved in the early, automatic encoding of affective information (Reker et al., 2010; Suslow et al., 2016). It is likely, therefore, that the usually fast, bottom-up, implicit processing of affect is disrupted to a significant extent in those with alexithymia.

Several authors now suggest that the emotion processing difficulties often seen in autism may well be caused by co-occurring alexithymia, rather than being a deficit fundamental to ASD itself (Cook et al., 2013; Kinnaird et al., 2019; Poquérusse et al., 2018). If this theory proves correct, the significant proportion of the autistic population with alexithymia may experience fundamental disruptions to the implicit processing of affect (Vermeulen et al., 2006). During social interactions, such disruptions could lead to important emotion-based information being omitted from what is learned. As a consequence of this omission, others' dispositions and intentions (which would normally be processed automatically during implicit learning) would be less available to integrate with other information to guide subsequent cognitive processes. Such a proposal, alongside evidence that social reinforcement may exert a weaker influence on subsequent behaviour (Delmonte et al., 2012 – see section 3.2.3, below), seems consistent with the well-established notion of autism-related 'weak central coherence' (Frith, U., 1989); a lowered ability to integrate information from different sources in order to 'see the bigger picture'.

Like autistic traits, alexithymic traits are normally distributed throughout the general population (Franz et al., 2008; Salminen et al., 1999). Furthermore, in both TD and autistic samples, significant positive correlations have been demonstrated between autistic and alexithymic traits (Barros et al., 2022; Cuve et al., 2021; Szatmari et al., 2008; Vaiouli & Panayiotou, 2021). Taken together, evidence therefore suggests that autistic individuals (and people higher in autistic traits) may be more likely to suffer disruptions to emotion processing, theoretically undermining their (possibly otherwise intact) ability to acquire social knowledge in a fast, automatic and effortless way. Because of alexithymia's high prevalence within the autistic population (Kinnaird et al., 2019), it certainly seems plausible that this mechanism could contribute to the social difficulties characteristic of ASD.

3.2.3. Implicit versus explicit theory of mind

Theory of mind (ToM) is broadly defined as the cognitive ability to process the mental states, emotions and beliefs of others (Baron-Cohen, 2000; Carlson et al., 2013; Frith, U., 1994). This ability is believed to underlie understanding and prediction of others' behaviour and is therefore considered an important facilitator of effective social communication. Following the introduction of the 'false belief' task (Wimmer & Perner, 1983), and the seminal finding that autistic children underperformed on it (Baron-Cohen et al., 1985b), autism has, rightly or wrongly, long been associated with deficient ToM processing (Gernsbacher & Yergeau, 2019).

In the classic 'Sally-Anne' false belief task, participants are introduced to two puppets; Sally and Anne. The (child) participant sees Sally place a marble into a basket before leaving the scene. However, Anne then moves the marble to a box. Sally returns to the scene and the participant is asked where Sally will look for her marble. If the participant indicates the box (the actual location of the marble), rather than the basket (where Sally would believe her marble to be), the child would have failed to demonstrate a working ToM (Baron-Cohen et al., 1985).

Based mainly on evidence from false belief tasks, it was initially suggested that a fundamental ToM deficit (also referred to as 'mindblindness') was shared universally by those with autism (Baron-Cohen, 1991). However, numerous studies have since shown that more linguistically able autistic participants, particularly those without an intellectual disability, are able to pass classic false belief tasks (Bauminger & Kasari, 1999; Buitelaar et al., 1999; Gernsbacher & Yergeau, 2019; Happé, 1995). This finding is understandable when one considers that classic false belief tasks, like the 'Sally-Anne', require participants to make an explicit judgement about a character's belief (with just two options available) in the absence of time pressure.[10]

As discussed previously, autism may be associated with a propensity to use slower, more deliberate strategies in situations that would usually elicit implicit processing (Klinger et al., 2007; Zwart et al., 2017). During an explicit ToM task, high-functioning autistic participants (and, indeed, non-autistic controls) would have ample opportunity to deduce the ramifications of characters' false beliefs, even if they were unable to do so in a rapid, non-conscious way (Livingston & Happé, 2017).

However, as discussed in Chapter 1, it would be too slow and cognitively demanding to consciously track others' mental states in real social environments. Instead, implicit automatic processes are believed to underly effortless 'social intuition' (Lieberman, 2000). In line with this suggestion, limited evidence does indicate a possible dissociation between implicit and explicit ToM 'systems'. Spontaneous, implicit monitoring of others' mental states may develop earlier in life than explicit ToM (Southgate et al., 2007), with several authors suggesting that the two systems continue to operate separately (Apperly & Butterfill, 2009; Frith, C. D. & Frith, 2008). Furthermore, while explicit ToM appears to

[10] More recently, Paul et al. (2021) showed that, instead of relying on the binary outcome of a Sally-Anne-like task, more subtle individual differences, including those associated with autistic traits, were detected after recording the speed of response to 'location' questions.

remain functional in HFA (as assessed by classic false-belief tasks), the same may not be true of implicit ToM processes.

Senju and colleagues (2009) conducted a study in which TD and Asperger participants, all of whom had passed a standard false-belief task, viewed videos of false belief scenarios while their gaze was monitored by eye-tracking equipment. The scenarios resembled those used in the Sally-Anne task, with an object being moved from one location to another while an actor looked away. Shortly afterwards, the actor returned their attention to the scene and attempted to retrieve the object. No instructions were given to participants, who simply watched the scenarios unfold. Senju and colleagues found that, just before the actor attempted to retrieve the object, TD participants looked in anticipation to the 'belief-congruent' location, indicating their understanding of the actor's false belief. Conversely, while the Asperger group also showed evidence of anticipatory looking, no bias toward the belief-congruent location was observed. Similar autism-related differences in anticipatory looking behaviour have since been reported in children (Senju et al., 2010) and in adults (Schneider et al., 2013, 2014). It is possible, therefore, that autistic adults may not implicitly process others' mental states (and spontaneously anticipate the person's intentions) to the same extent as TD adults. Such findings have prompted suggestions that an absence of spontaneous implicit ToM processing may contribute to the real-world social difficulties faced by those with HFA, despite their seemingly intact ability to comprehend others' mental states in traditional experimental settings (Schneider et al., 2013; Senju, 2012).

The studies cited here indicate that implicit and explicit ToM systems operate separately, and that individuals with autism may not spontaneously engage in implicit mental state processing. However, the very existence of two parallel ToM systems remains a subject of debate. Attempts have been made to replicate several anticipatory-looking implicit ToM studies using non-autistic participants across various age ranges (Kulke et al., 2018a, 2018b). For a large proportion of the paradigms re-tested, original significant results were not replicated, and the researchers found no evidence of convergent validity between paradigms. Kulke et al. concluded that the different tasks may not be "*tapping the same capacity of an implicit Theory of Mind*" and that "*the results from implicit Theory of Mind tasks should be treated with caution*" (Kulke et al., 2018a). Therefore, while a limited number of studies indicated autism-related differences in ‘implicit ToM’ processing, determining whether this ‘separate’ cognitive system truly exists requires further investigation.

Nevertheless, a recent meta-analysis of 110 ToM studies found that autistic participants underperformed across a broad range of tasks (Gao et al., 2023). While differences in ToM task performance may be moderated, in many cases, by other (non-ToM-related) attributes, such as intelligence, language comprehension and vocabulary (Gao et al., 2023; Gernsbacher & Yergeau, 2019), it remains possible that autistic individuals show a reduction in spontaneous mental state processing. With implicit ToM monitoring reduced (or absent), it would seem to follow that social learning would also be disrupted. For example, if someone did not automatically monitor others’ emotional states, their ability to learn implicitly which actions provoked disapproval (or amusement, boredom or surprise) would also be compromised. Therefore, similar to the disrupted processing of emotions (see section 3.2.2), autism-related ToM processing differences could theoretically harm implicit learning within the social domain. This reduction in social learning may, consequently, promote the social difficulties common in autism.

In the studies that follow, constraining participants’ attention to the eyes (see section 3.2.1) was predicted to affect implicit social learning from facial cues. If high-autistic-trait participants were affected by this manipulation to a greater extent than those lower in autistic traits, autism-related attentional factors would be implicated as moderators of implicit social learning. Furthermore, if autistic traits correlated negatively with learning regardless of any manipulation in attention, social cognitive factors related to autism, such as (but not restricted to) those discussed here, would also be implicated as moderators of implicit social learning.

3.3. Summary

Numerous studies have shown that high-functioning autistic adults perform similarly to TD controls on a wide range of ISL measures. This finding prompted conclusions that implicit learning remains intact in ASD. However, traditional ISL measures rarely feature socially relevant stimuli, leaving open the possibility that autism-related implicit learning difficulties reside specifically within the social domain. Providing support for this suggestion, Hudson et al. (2012) demonstrated that higher autistic traits were associated with reduced social implicit learning from emotional facial cues.

Three main mechanisms were discussed in this chapter that may limit social implicit learning in people with autism.

1. Individuals with autism (or those higher in autistic traits) may not prioritise attention toward socially salient cues to the same extent as those lower in autistic traits. This attentional difference could result in social learning opportunities' being missed. In particular, reduced monitoring of others' eyes might cause autistic individuals to miss informative cues that would otherwise aid implicit social learning.
2. Fundamental differences in cognition, related to autistic traits, may also lessen the availability of social information for implicit learning. In particular, the significant proportion of the autistic population with alexithymic traits may experience disruptions to the implicit processing of affect. A diminished ability to process emotions may fundamentally undermine the ability to discern others' attitudes and intentions. In turn, any implicit learning that requires an accurate representation of others' attitudes would be compromised. Disrupted processing of affect may therefore harm implicit learning particularly within the social domain.
3. Similarly, reduced automatic ToM processing (another potential ASD-related cognitive difference) might also harm social learning. High-functioning autistic adults have demonstrated the ability to effortfully track others' mental states during traditional false belief tasks. However, an absence of (or reduction in) spontaneous implicit 'mentalising' may contribute to the real-world social learning difficulties faced by autistic individuals.

The remaining studies in this thesis were designed with two overarching objectives. The primary goal was to investigate whether higher autistic traits (or clinical ASD diagnoses) were associated with reduced implicit learning of social information. Few studies have investigated social implicit learning and its relationship to autism, so more evidence is required to ascertain whether an implicit social learning deficit, or indeed any form of implicit learning deficit, is associated with the condition. An important secondary goal of the remaining studies was to investigate the potential mechanism behind any autism-related implicit learning differences found. It was beyond the scope of this thesis to tease apart any specific influences of alexithymic traits and spontaneous mentalising on social implicit learning. However, the following studies *were* designed to examine whether any implicit social learning differences detected were better explained by attentional differences or by broader social cognitive factors associated with autism.

Chapter 4. Study 2: Implicit social learning from dynamic facial cues

4.1. Introduction

Autistic adults and TD controls have performed similarly on a wide range of implicit learning paradigms, prompting conclusions that implicit learning remains intact in autism (Foti et al., 2015; Obeid et al., 2016). However, ISL tasks have rarely assessed learning in the social domain. The current study was designed to investigate whether higher autistic traits, in a TD sample, were associated with a reduced ability to learn social information implicitly. The study adopted, and built upon, social learning paradigms developed by Hudson et al. (2012) and Macinska (2019), which are described below.

Hudson and colleagues (2012) conducted a gaze-cueing study that indirectly tested implicit learning of social dispositions from facial cues. During a learning phase, Hudson et al.'s participants (all TD) repeatedly observed two computer-generated human-like identities whose gaze direction and facial expressions conveyed either a positive or negative disposition toward the viewer. For an identity to portray a positive disposition, an initial expression of happiness was combined with gaze directed towards the participant. This then transitioned to an expression of anger during which the identity's gaze was averted. The positive identity's pro-social disposition could be inferred correctly whether the video clip was played as described or in reverse (as it was on half of the trials), as the identity always smiled when looking toward the participant but showed anger while looking away. The opposite was true for the negative identity, which smiled when looking away from the participant but showed anger while looking towards them. To encourage sustained attention to the stimuli, a secondary task required participants to press the spacebar when the identity's gaze stopped moving close to the end of each trial. To prevent participants from responding without attending to the stimuli, catch trials were included in which the two identities displayed neutral facial expressions and executed no changes in gaze direction.

After the learning phase (32 video clips of each identity), participants completed a gaze-cueing task. An identity's face (with a neutral facial expression) was presented centrally with gaze averted either to the left or to the right. A target then appeared in a location either congruent or incongruent with the identity's gaze cue which participants had to react to as quickly as possible. Known as the 'gaze-cueing effect', people typically react faster when gaze cue and target location are congruent, rather than incongruent. The gaze-cueing effect is known to be moderated by social factors related to the cue provider (Dalmaso et al., 2020). Therefore, if participants had *not* learned each identity's social disposition during the learning phase, there should have been no difference in gaze cueing effect between the positive and negative identities. If, however, participants had implicitly learned the identities' social dispositions, Hudson and colleagues predicted a larger gaze cueing effect for the positive (pro-social/cooperative) identity than the negative (anti-social/uncooperative) identity. Participants had completed the AQ (Baron-Cohen et al., 2001b) before the task began and were allocated, via a median split, into low- and high-AQ groups before analysis.

Hudson et al. found that, in the low-AQ group, the antisocial identity elicited a significantly smaller gaze cueing effect than the pro-social identity. For the higher-AQ participants, however, there was no difference in gaze cueing effect between identities. Debriefing of participants reportedly indicated that they had developed no explicit awareness of the identities' social cues (during the learning phase), or explicit knowledge that the two identities held opposite social dispositions towards them. Hudson et al. therefore concluded that the low-AQ participants had implicitly learned the identities' dispositions, and that this learning had influenced reaction speeds to the two identities' gaze cues. Conversely, no implicit learning had occurred for the participants with higher autistic traits, negating any influence of the two separate identities on the gaze-cueing task (Hudson et al., 2012).

Macinska (2019, Experiment 1), in a study that formed part of her PhD thesis, used a similar method to Hudson et al. to investigate the relationship between implicit social learning and autistic traits. However, to increase the ecological validity of Macinska's study, animated/morphed photographs of real people (rather than computer generated identities) were used as learning-phase stimuli. Study 2 of this thesis adopted the same type of stimuli as Macinska, the creation of which is detailed in section 4.2.2. Aside from using photographic stimuli, and the absence of a gaze tracking secondary task to monitor participants' attention, Macinska's learning phase was very similar to Hudson et al.'s. Two characters (40 presentations of each) conveyed either pro- or anti-social dispositions via combinations of gaze directions and maximally happy/angry facial expressions.

Following Macinska's learning phase, participants gave verbal responses to questions designed to assess; a) explicit awareness of the social cues, b) ability to differentiate between the characters and c) ability to identify the emotions displayed by the characters. However, as in Hudson et al. (2012), details of how answers were scored were not included in the report. Participants then completed a test phase in which they made judgements about whether smiling or angry-faced morphed composites of the two characters more closely resembled the positive or negative character from the learning phase.[11] Afterwards, participants completed a likeability questionnaire for each character. Answers to questions, including '*How much do you like this person?*' and '*How much does this person like you?*', were scored on a '0 to 100' rating scale.

With data from the explicitly aware participants removed (around 10% of participants), Macinska found that the learning phase *had* influenced the characters' perceived likeability. Although the remaining participants were seemingly unaware of the earlier social cues, they nevertheless rated the positive character as more likeable than the negative character. While Macinska's indirect (morph composite rating[11]) measure indicated that higher AQ scores were associated with diminished implicit social learning, no such effect was found for the (more direct) measure of likeability. Both low- and high-AQ participants showed a similar preference for the positive character, indicating that the social judgements of both sets of participants had been equally affected by implicit learning during the learning phase.

The current study was designed, in part, to replicate Macinska's experiment. However, several methodological changes were introduced to rectify uncertainties in both Hudson et al.'s and Macinska's study designs. Several of these changes were relatively minor but

[11] As this method of testing is of limited relevance to the current study, it is not described here in detail. In summary, however, Macinska found that implicit social learning created a perceptual bias in the low AQ participants only. In the higher AQ group, morph ratings showed no evidence of a perceptual bias in line with the characters' learning phase social cues. Essentially, there was evidence of reduced implicit social learning in the higher AQ participants (see Macinska, 2019, pp. 55-63 for further details).

were introduced to clarify methods and thus increase the study's replicability. For example, more formal criteria were introduced to select the actors that portrayed the positive and negative characters in the learning phase. Similarly, the criteria employed for assessing and analysing participants' explicit awareness of the social cues are described in detail. Other changes were introduced in response to COVID-19 restrictions. Because data collection took place online, Study 2's procedure was kept deliberately brief. Therefore, only likeability ratings (as opposed to morph judgements or gaze cue reaction times) were used to quantify implicit learning in the current study.[12] However, other methodological changes were also introduced to tighten control of variables that might otherwise have affected the study's results. These more fundamental amendments to the methodology are discussed below.

4.1.1. Anger versus disgust as a social signal

In Hudson et al. (2012) and Macinska's (2019) studies, the pro- and anti-social characters conveyed their dispositions via idiosyncratic combinations of gaze directions and maximally happy or angry facial expressions. However, angry faces communicate not only social information but stimulate neural responses associated with threat detection (Feldmann-Wüstefeld et al., 2011; Mattavelli et al., 2014). Furthermore, the 'angriness' of an angry face is known to be intensified when combined with direct gaze (Adams Jr & Kleck, 2005; Sander et al., 2007).

As discussed in Chapter 3, many autistic adults avoid eye contact because it, alone, makes them feel threatened and anxious (Tanaka & Sung, 2016). Learning-phase videos that included regular direct eye contact *and* displays of anger (combined in the anti-social character, but present in both characters) may have induced threat-based anxiety in Hudson et al.'s and Macinska's high-AQ participants. Importantly, threat-based anxiety is known to disrupt participants' implicit learning of statistical regularities in their environment (Rowe et al., 2023), a phenomenon that is enhanced in individuals with higher trait anxiety (Browning et al., 2015). Elevated levels of anxiety are often

[12] Hudson et al.'s (2012) participants reacted as quickly as possible to gaze cues, whereas Macinska's and Study 2's participants made conscious judgements in the absence of time pressure. It could therefore be argued that Hudson et al. used an implicit (fast, automatic) measure of implicit learning, whereas the current study uses an explicit (slow, deliberate) measure. Later in this thesis, Study 5 measures implicit learning using both implicit and explicit methods. A discussion of how 'method of assessment' may have affected outcomes (in all of these studies) can be found later in the thesis (see section 8.2).

associated with autism (Hollocks et al., 2019; Jolliffe et al., 2023). It therefore seems possible that, in Hudson et al.'s and Macinska's studies, automatic threat responses may have induced anxiety that then interfered with the high-AQ participants' implicit learning of social information.

Both of these studies produced evidence that implicit social learning was reduced in high autistic trait individuals. However, because Hudson et al. and Macinska used 'anger' during their learning phases, there may be two alternative explanations for their findings. High-AQ participants may have demonstrated a genuinely reduced ability for implicit social learning. However, similar learning outcomes could conceivably result from anxiety-inducing threat responses (promoted by the characters' angry faces) interfering with the high-AQ participants' (otherwise intact) ability to learn social dispositions implicitly.

To resolve this issue, the negative character in the current study conveyed their disposition using a disgusted, rather than angry, facial expression. In a social context, disgust is usually expressed towards those who have violated important moral codes and those who are considered to have a fundamentally unpleasant character (Giner-Sorolla et al., 2018; Kupfer & Giner-Sorolla, 2017). While an overt show of disgust does not communicate threat in the same way as anger (Mattavelli et al., 2014), it is seen as a powerful social signal often associated with prejudicial attitudes (Skinner & Hudac, 2017; Terrizzi Jr et al., 2010) and social disapproval (Amir et al., 2005; Boksem et al., 2011). The disgust directed at participants by the negative character was therefore still expected to influence (decrease) later likeability ratings. However, by using this more subtle expression of an anti-social attitude, the potential confound of anger-based threat detection was eliminated. It was still predicted, though, that participants' autistic traits would correlate negatively with the current study's measure of implicit social learning.

4.1.2. Gaze monitoring secondary task

During social interactions, the eye region provides important information about others' mental states. However, people who are high in autistic traits have been known to divert their attention away from the eyes, potentially missing facial cues that would otherwise aid implicit social learning (see section 1.5.4). Hudson et al. (2012) encouraged (and monitored) sustained attention to learning-phase stimuli by requiring participants to press the spacebar whenever an identity's gaze stopped moving. Because this task required participants to attend almost constantly to the characters' eyes, gaze avoidance behaviour was effectively designed out of the experiment. This secondary task was missing from Macinska's learning phase, but a version of it was reintroduced for the current study. Monitoring participants' attention was particularly important for the current study because, to prevent COVID restrictions from impeding data collection, testing took place entirely online.

Participants were, once again, required to press the spacebar whenever a character's gaze stopped moving close to the end of each trial. Catch trials were included where no change of gaze direction occurred and therefore no response was required. However, in the current study, a third 'neutral distractor' character appeared during the learning phase. This character was introduced to reduce participants' explicit focus on the positive and negative characters and, importantly, to facilitate *all* of the secondary task catch trials (see section 4.2.2 for details). To facilitate catch trials in Hudson et al.'s study, the positive and negative identities occasionally appeared with neutral facial expressions and executed no change in gaze direction. The addition of the neutral character (in the current study) allowed the positive and negative characters to portray their social dispositions *consistently*, possibly facilitating greater social learning. Crucially though, the use of the third character also eliminated any effect that sustained direct gaze (and neutral facial expressions) may have had on the positive and negative characters' later likeability ratings.

4.1.3. Task order and likeability assessment

Macinska (2019) found that higher autistic traits were associated with poorer performance on an indirect measure of implicit social learning (morph composite ratings), but not on the more direct measure of character likeability. However, it is worth noting the order in which tasks were completed in Macinska's study. The learning phase was immediately followed by the following questions: '*(1) "Could you describe what you just have seen?" (2) "How many different identities did you see?" (3) "What can you tell me about their facial expressions?" (4) "What can you tell me about their gaze direction?" (5) "Did you detect certain patterns between facial expressions, gaze* *directions and identities?"'* (Macinska, 2019, p. 55). It could be argued that these questions drew explicit attention toward the learning phase social cues and the potential differences between the two 'identities' (characters). Following these questions, participants completed a morph composite rating task. It was not until after this task, and now several minutes after the conclusion of the learning phase, that participants rated the positive and negative characters for likeability.

It seems possible that, in addition to the learning-phase stimuli, the questions, morph composite task *and* the amount of time elapsed since the learning phase may have affected character likeability ratings. In the current study, likeability was assessed using selected items from a published likeability scale (see section 4.2.3). Importantly, though, character likeability was assessed shortly after the learning phase, and before participants were asked questions that potentially increased the explicit salience of the facial cues.

4.1.4. Exclusion criteria testing

As mentioned in the preceding section, Macinska (2019) asked her participants questions to assess their ability to differentiate between characters and to identify the task-relevant emotional facial expressions. These questions were intended, in part, to test participants against important exclusion criteria. Using this type of paradigm, social learning could not occur unless participants understood that they had seen two separate characters during the learning phase. Likewise, only participants that could identify happy and angry facial expressions would have been able to learn the characters' 'hidden' dispositions. It was therefore important that participants who did not meet these criteria (plus those who had become explicitly aware of the learning phase cues) were excluded from later analyses. However, details of how participants were assessed against these exclusion criteria were missing from the report.

While it should have been easy for TD participants to differentiate between just two characters, and to correctly identify maximally happy and angry facial expressions, these are potential areas of difficulty for people with autism. Autistic children and adults have demonstrated less reliable differentiation between faces, and less accurate memory for faces, than TD controls (Minio-Paluello et al., 2020; Sasson, 2006; Tang et al., 2015; Wilkinson et al., 2010). As discussed in Chapter 3, a significant proportion of autistic individuals also have difficulty processing emotions, which can hinder recognition of human emotional facial expressions (Leung, F. Y. N. et al., 2022). The current study therefore describes in detail how exclusion criteria were assessed, so that its methods can be replicated in future research.

4.1.5. Summary

Study 2 was designed to investigate whether higher autistic traits, in a TD adult sample, related to poorer implicit social learning from dynamic facial cues. Previous studies demonstrated that implicit learning from two characters' emotional facial cues could affect participants' performance on subsequent gaze cueing, perceptual judgment and likeability rating tasks. Evidence from the gaze cueing and perceptual judgment tasks indicated that higher levels of self-reported autistic traits related to reduced implicit social learning. However, this relationship was not observed on the more direct measure of character likeability.

Several factors were identified that may have contributed to this discrepancy. In particular, the use of anger as the 'negative emotion' may have caused implicit threat detection (rather than/in addition to *social* learning) to affect the outcome of the measures. As such, 'disgust' was utilised, in the current study, as a more subtle expression of a character's social disapproval. A gaze monitoring secondary task was also re-introduced to the learning phase to encourage and monitor participants' attention to the facial cues. Several other methodological adjustments were implemented to clarify procedures and to help control potentially confounding variables. With these changes in place, it was predicted that dynamic facial cues, designed to convey pro- and anti-social attitudes, would significantly influence character likeability ratings in line with each character's portrayed social disposition. However, if autism is associated with a reduced ability to acquire social knowledge implicitly, the magnitude of this effect should correlate negatively with a measure of self-reported autistic traits.

4.2. Method

4.2.1. Participants

Approval for this study was granted by Nottingham Trent University's College Research Ethics Committee. Because of ongoing concerns about coronavirus infection rates in the UK, the study was designed to be completed online. 57 participants (8 male, 48 female and 1 other/non-binary, aged 18 to 76 years old, mean age = 26, SD = 13.89) took part in testing, all of whom were recruited via social media channels or via Nottingham Trent University's Psychology Research Participation Scheme. None of the participants reported an official diagnosis of any autistic spectrum condition. Participants were incentivised to take part in the research with the chance to win a first prize of £100 in Amazon vouchers, or one of two smaller prizes of £20 in Amazon vouchers. NTU psychology students who completed the online study had the option to choose between the prize draw and receiving research participation scheme credits. All participants provided consent via an online form before taking part in the study.

4.2.2. Task stimuli

The current study used short video clips showing faces transitioning from one facial expression to another. These stimuli were created by adapting images taken from the Warsaw set of Emotional Facial Expressions Pictures (WSEFEP, Olszanowski et al., 2015). The WSEFEP is a database of colour 'head and shoulders' images of actors displaying a range of emotional facial expressions. Unlike other photo sets, the WSEFEP was created by training volunteers to express genuine 'felt' emotions while being photographed. This method was chosen to ensure that the pictures closely represented natural emotional facial expressions, thus increasing the set's ecological validity. The final WSEFEP includes only those photographs that were validated successfully by over 1,300 independent assessors. Validation criteria for photographs included high levels of assessors' agreement regarding the emotion being displayed, as well as high ratings for the purity and intensity of that emotion (see Olszanowski et al., 2015 for details). Following the validation process, 210 photographs of 30 individuals were retained to form the final set.

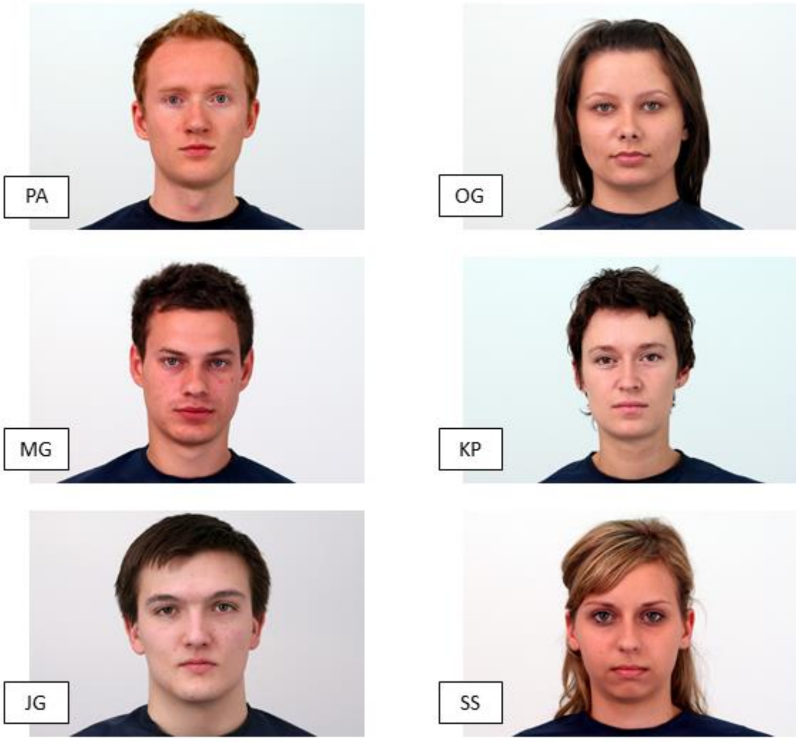
Photographs of 6 actors (3 male and 3 female) were selected from the WSEFEP for use in the current study (see **Figure 9**). These images, which portrayed 'joy', 'disgust', 'surprise' and 'neutral' facial expressions, were selected after eliminating all photographs that achieved less than 75% assessor agreement (regarding the emotion being displayed) during the WSEFEP validation process. For the particular images chosen, judges' agreement ranged from 76% to 97%, with a mean agreement level of 89% (94% for the task-critical images which portrayed joy and disgust). These figures compare favourably to the 82% agreement level achieved across the full range of photographs within the WSEFEP (Olszanowski et al., 2015). As mentioned, instead of using still images, the current study used short videos in which the actors' facial expressions and gaze directions changed dynamically. These video clips were created in the following way.

All photographs in the WSEFEP featured actors looking directly at the camera. GIMP 2.10.22 software was used to create additional versions of the selected images in which each actor's gaze was averted to their left (observer's right). To create a dynamic (moving) video, two static images of the same actor were then morphed together using Sqirlz Morph 2.1 software, resulting in a smooth transition from one facial expression to another. Each video was 2,500ms long and recorded at 60 frames per second. In every video, a static image was first shown for 1,000ms, followed by a dynamic 500ms morphed transition to the second static image, which was again displayed for 1,000ms. For each actor, the relationship between facial expression and gaze direction was manipulated to provide an implicit cue regarding their social disposition toward the viewer.

To portray an actor as having a positive disposition, an initial expression of joy was combined with gaze towards the participant. This configuration then transitioned to an expression of disgust during which the actor's eyes were averted to the side. Importantly, the actor's positive disposition could be inferred correctly whether the video was played as described or in reverse (starting with an expression of disgust with eyes averted, before transitioning to a happy expression with direct gaze). In other words, whether the video was played forwards or backwards, the 'positive character' (regardless of the particular actor portraying them) always smiled when looking toward the participant, but grimaced while looking away (see **Figure 10**). For an actor to portray the ‘negative character’, an initial expression of disgust was combined with gaze towards the participant. This then transitioned to an expression of joy during which the actor looked away to the side. Again, the negative character’s disposition toward the participant could be inferred whether the video was played as described or in reverse.

Figure 9

Actors that appeared in learning-phase stimuli



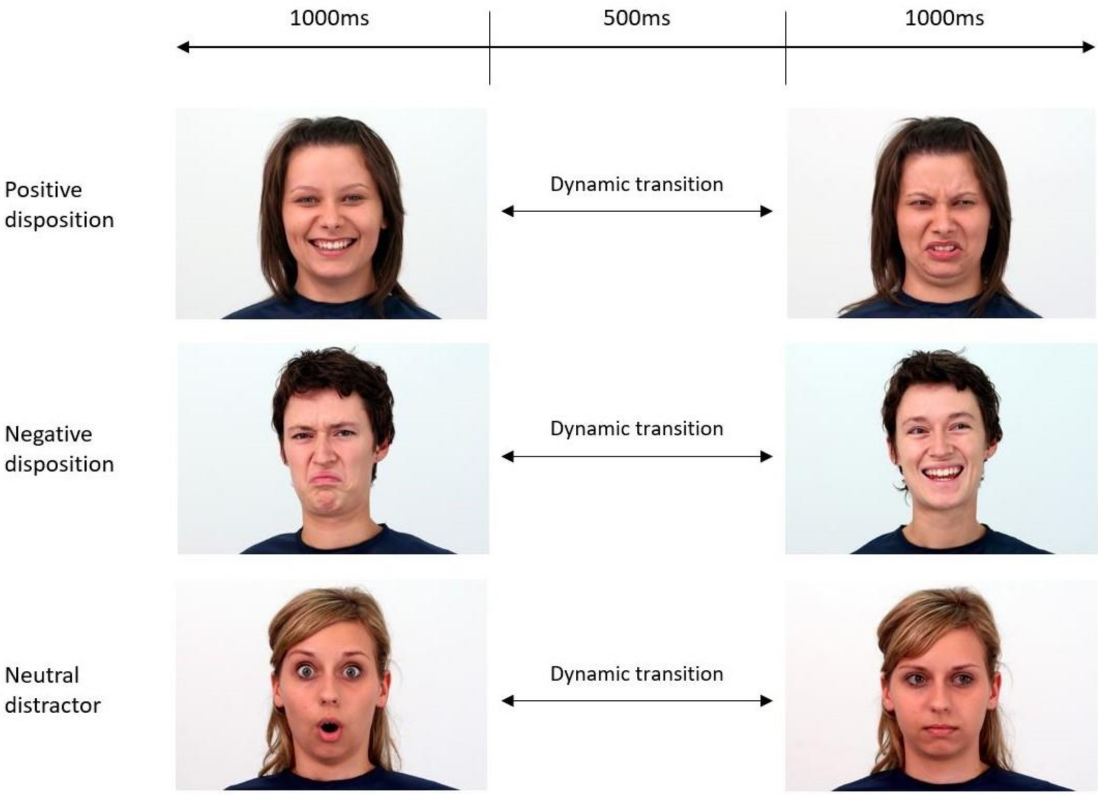
Note. WSEFEP actors were selected for the current study based on high levels of agreement on the emotions being portrayed. The three males (PA, MG and JG) and three females (OG, KP and SS) are pictured here with neutral facial expressions. Actors’ initials were not included in task stimuli.

During the learning phase of the task, each participant saw three actors of the same sex. One actor consistently displayed ‘positive’ disposition cues (they were the positive character) while another always displayed ‘negative’ cues (they were the negative character). A third actor was included as a neutral distractor. Importantly, both positive and negative characters looked towards and away from participants for the same amount of time. Both characters also displayed disgusted and happy facial expressions for the same amount of time. In addition, each character's video was played in forward and reverse order an equal number of times. Therefore, participants could not infer characters' social dispositions based on simple cues, such as the emotion most frequently displayed, or the last (most recent) emotion displayed in video clips. Indeed, social disposition learning could only take place if participants acquired implicit (or possibly explicit) knowledge of each character's individual combination of facial expressions and gaze direction cues.

As mentioned, a third 'neutral distractor' character also appeared during the learning phase. This character was included for two reasons; 1) to reduce participants' explicit focus on the positive and negative characters (thus decreasing the likelihood that participants would gain explicit awareness of the social cues), and 2) to facilitate catch trials in a supplementary task, as described in the following section. The distractor character displayed neutral and/or surprised facial expressions, sometimes with a change of gaze direction and sometimes with no eye movement at all. In earlier iterations of the task, the distractor displayed only a neutral facial expression. However, the artificial introduction of eye movement (which was required for the catch trials – see below) to an otherwise eerily still face was judged to create a disconcerting effect which could potentially affect participants' concentration during the learning phase. Therefore, distractor characters displayed surprised and neutral facial expressions, combined with changes of gaze direction. This allowed for gaze direction changes that were more in keeping with those displayed by the positive and negative disposition characters. 'Surprise' was selected as the additional emotion for the distractor because it purveyed no obvious inherent social disposition information. In any case, participants' feelings toward the distractor character were not expected to influence their learning of the other characters' social dispositions.

Figure 10

An example set of female learning-phase stimuli



Note. During the learning phase, participants saw three actors of the same sex. A character was portrayed as having a positive disposition by smiling when looking at, but showing disgust when looking away from, the participant (see actor OG, top row). Another actor displayed negative disposition cues by grimacing when looking at, but smiling when looking away from, the participant (see actor KP, middle row). For the positive and negative disposition characters, half of the video clips began with direct gaze (as shown above) and half began with gaze averted. A 'neutral' character was included as a distractor (see actor SS, bottom row). They displayed surprised and neutral facial expressions combined in various ways with direct and averted gaze. The distractor character never displayed happy or disgusted facial expressions.

4.2.3. Task procedure

All tasks were developed using Gorilla Experiment Builder. Testing took place entirely online, using a computer of the participant's choice. Participants were prevented from using a mobile phone or tablet computer to complete testing, though the task was not able to specify boundaries for computer screen size. All information and task instructions were provided in writing. Participants were first presented with information pages that described the experiment as a study investigating the 'processing of facial features and emotional facial expressions'. Aside from the omission that the study's main interest was in the implicit learning of social cues, all information provided was accurate. Participants were asked to complete the study in a quiet location where they would remain undisturbed for the 15-to-20-minute task duration. Following completion of an online consent form, participants provided demographic information, including whether they had ever received a diagnosis for autism or Asperger's. Before beginning the task, participants confirmed that they had normal vision, or were wearing glasses/contact lenses that corrected their vision to normal. After testing (in this and all subsequent studies), participants were presented with a debrief outlining the true purpose of the experiment.

Learning phase: Participants were informed that they were about to see a series of short video clips featuring faces. Videos were presented centrally and occupied a large proportion of the screen. Similar to Hudson et al. (2012), a supplementary task was introduced to encourage sustained attention and to later identify participants who were not attending to the stimuli. Participants were instructed to watch the videos closely for eye movement. If the video featured a change of gaze direction, they should press the spacebar as soon as the eye movement ended. If the participant saw no eye movement in the video clip, they should not press the spacebar. To prevent participants from repeatedly pressing the spacebar without attending to the video clips, catch trials were included which contained no eye movement. Catch trials all featured the neutral distractor character so as not to interfere with participants' learning of the positive and negative characters' social dispositions. Because changes of gaze direction completed just 1,000ms before the end of each video clip (and videos were played with a very brief pause between them – see below) accurate responses on this task required participants to attend to the screen almost constantly. The supplementary task also ensured that participants attended closely to the eye region of the characters, an important consideration given that reduced attention to others' eyes is a well-established hallmark of autism (Moriuchi et al., 2017). To optimise learning opportunities, every video clip was shown in full, whether or not the participant responded correctly by pressing (or not pressing) the spacebar.

Participants first completed 10 'practice trials' before proceeding with the remainder of the task. Because the main purpose of the supplementary task was simply to encourage attention to the stimuli, these initial 10 trials formed (unbeknownst to participants) part of the main learning sequence. During the learning phase, participants viewed 36 video clips of the 'positive disposition' character (18 played forward and 18 in reverse) and 36 of the 'negative disposition' character (again, 18 played forward and 18 in reverse). Clips were played in pseudo-random order intermixed with 24 video clips of the neutral 'distractor' character. Half of the neutral character's clips featured eye movement, while half featured no change of gaze direction and acted as catch trials (see **Table 3**). Throughout the presentation of stimuli (96 video clips in total), no character appeared twice in succession. Participants viewed videos featuring only female or only male actors (a condition assigned at random). Female actors OG and KP portrayed positive or negative dispositions (randomised between participants) while actor SS always featured as the neutral distractor. For participants viewing male video clips, PA and MG portrayed positive or negative dispositions (again, randomised between participants) with JG acting as the neutral distractor.

Table 3

Learning-phase video stimuli

Stimuli type (character's portrayed disposition toward participant)						
Positive (fwd)	Positive (rev)	Negative (fwd)	Negative (rev)	Neutral / distractor (with eye motion)	Neutral / distractor (no eye motion - catch trial)	Total
18	18	18	18	12	12	96

Note. Breakdown of video stimuli presented to participants. Each participant saw 3 actors of the same sex. One actor consistently displayed positive disposition cues, one actor consistently displayed negative disposition cues while a third distractor character remained neutral throughout the trials. As described previously, characters' social dispositions were portrayed consistently whether the video clips were played forward (fwd) or in reverse (rev).

To minimise the chance of participants developing explicit awareness of the social cues, the 2,500ms video clips were played in quick succession, separated only by a blank screen lasting 300ms. The only exception to this sequence was when a participant pressed the space bar in error during a catch trial or failed to press the space bar for a clip that featured eye movement. In these cases, participants were reminded of the task instructions (on screen for a minimum of 3000ms) and were then asked to press the spacebar to continue. For participants who followed the task instructions perfectly (and therefore made no errors), the learning phase lasted around 4 mins 40 sec.

Test phase: Immediately following the learning phase, participants were asked 'How many different individual people appeared in the video clips?'. Participants selected a number between 1 and 8 from a dropdown menu on screen. This question was asked to establish that participants had paid sufficient attention to the stimuli and could differentiate between the faces of the three actors featured. Participants were then asked to rate the positive and negative disposition characters (in randomised order) for 'likeability' using 5 items from the longer Reysen Likability Scale (Reysen, 2005). Participants were asked to respond to the following statements using an unmarked response slider, which ranged from 'Very strongly disagree' on the left (scored as zero) to 'Very strongly agree' on the right (scored as 100): 'This person is likeable', 'This person is approachable', 'I would ask this person for advice', 'I would like to be friends with this person' and 'This person is similar to me'. In a study using similar video stimuli, Macinska (2019) found that actors' portrayed dispositions were not correlated with physical attractiveness ratings. This aspect of 'likeability' was therefore not assessed in the current study.

Next, participants answered questions designed to assess whether they had gained explicit knowledge of the characters' social cues. They were shown an image of the neutral character and asked: 'In videos featuring this person, did you notice any patterns in their gaze direction and facial expressions?'. Participants selected either 'yes' or 'no'. If they selected 'yes', they were provided with a text box and asked to briefly describe any patterns that they had observed. This process was repeated for the positive and negative disposition characters (in random order). Following that, participants were shown randomised still images of the positive and negative character actors displaying 'disgust', 'joy' and 'neutral' facial expressions. For each image, participants were asked to select the word that best described the actor's emotion. The options were: 'surprise', 'happiness', 'sadness', 'neutral', 'disgust' and 'fear'. This measure was included to ensure that participants could correctly identify the emotions being displayed in the earlier video clips. It was assessed at this stage to ensure that labelling of the emotions did not draw explicit attention to this aspect of the stimuli during the learning phase. Finally, participants completed the Autism Spectrum Quotient Short Form (AQ-S, Hoekstra et al., 2011). The AQ-S is 28-item validated version of the longer AQ (Baron-Cohen et al., 2001b) which measures the degree to which adults with normal intelligence have traits associated with ASD. Participants responded to statements using a 4-point Likert-type scale, with answer categories ranging from ‘‘1 = definitely agree’’ to ‘‘4 = definitely disagree’’. Item scores could then be summed, resulting in a minimum AQ-S score of 28 (indicating no autistic traits) and a maximum score of 112 (indicating full endorsement of all autistic trait statements).

Summary: In a previous study, Macinska (2019) demonstrated that 40 presentations of similar video stimuli elicited learning of characters’ dispositions, with around 10% of participants developing explicit awareness of the social cues. The current study attempted to replicate Macinska’s findings using an online task (with no in-person participant supervision) and slightly fewer presentations of the video stimuli. The novel task also used (mostly) different actors to those used by Macinska, all of whom were selected solely for their capacity to portray the relevant emotions. Higher levels of self-reported autistic traits were predicted to correspond to decreased learning from the characters’ implicit social cues.

4.3. Results

4.3.1. Data reduction

Inattention to stimuli: Throughout the learning phase of the task, 12 catch trials were inserted into the sequence of videos in which the neutral character’s gaze direction did not change. In contrast to the majority of trials, participants responded correctly to catch trials by *not* pressing the spacebar. Participants were judged to have been sufficiently inattentive to merit exclusion if they responded correctly to fewer than half of the catch trials.[13] One participant was excluded for this reason. Participants would also have been excluded if they had failed to respond correctly (by pressing spacebar) to at least 80% of non-catch trials. However, all participants surpassed this threshold, achieving a mean response accuracy (across all participants) of 98.1%.

Face differentiation: Immediately following the task's learning phase, each participant was asked how many different individual people had appeared in the video clips (correct answer: 3). This was to establish that participants could differentiate between the faces of the actors featured. While 43 of the remaining 56 participants (77%) answered correctly, 10 participants (18%) believed the video clips had featured 4 actors, while 3 participants thought that they had observed 5 or 6 individual actors. Given the lower-than-anticipated accuracy of answers to this question, participants' data were not excluded from further analysis unless the participant believed they had observed *fewer* than the three actors featured. In the current study, all participants stated that they had seen *at least* three individual people in the video clips. Therefore, no participants were excluded for this reason.

Explicit awareness: To assess explicit knowledge of the positive and negative characters' social cues, participants were asked to describe any patterns observed. Throughout the task's learning phase, the 'positive character' smiled when looking at, but showed disgust when looking away from, the participant. The opposite pattern was true for the 'negative character'. Participants were scored as having developed explicit awareness if they unambiguously referred to at least one 'half' of a character's social cue contingencies. For example, when a participant wrote that the positive character was '*looking to the right and frowning*', they were scored as explicitly aware because they had referred to the positive character always looking disgusted while their gaze was averted. Likewise, the participant who wrote that the negative character '*turned to one side to smile*' (smiled only when gaze was averted) was also scored as having developed

[13] This method of monitoring attention was introduced by Hudson et al. (2012), who excluded participants with an *overall* response accuracy (across all learning phase trials) of under 90%. In the current study, just 12 of the 96 trials (12.5%) were 'oddball' catch trials that required participants not to respond. Therefore, if a completely inattentive participant pressed spacebar during every learning phase trial, their response accuracy would be 87.5% (very close to Hudson et al.'s inclusion criterion). As the current study was conducted online, it was considered particularly important to monitor attention carefully, hence the 50% cut-off criterion for catch trials. This figure was chosen, following pilot testing of the task, to allow several understandable mistakes by attentive participants, but to identify those who seemed to be making more consistent errors due to inattention.

explicit awareness. Just 2 of the remaining 56 participants (3.6%) showed clear evidence of developing explicit awareness for *both* positive *and* negative characters. A further 7 participants demonstrated explicit awareness of *either* the positive or negative character's cues. An unpaired two-samples t-test was conducted to check whether participants' self-reported autistic traits (AQ-S scores) were related to their development of explicit awareness. There was no significant difference in AQ-S scores ($t_{(55)} = 0.0025$, $p = .998$) between explicitly aware participants (M = 61.22, SD = 5.36) and those who remained unaware of the social disposition cues (M = 61.23, SD = 8.05). The data from all 9 explicitly aware participants (15.8% of the original 57 participants) were excluded from subsequent analyses. This was because any learning of social dispositions by these participants was unlikely to be entirely implicit in nature.

Facial expression identification: Participants were asked to identify the facial expression shown in images of the positive and negative character actors. There were 6 images in total in which 'disgust', 'joy' and 'neutral' facial expressions were displayed. Participants would have been excluded if they were unable to identify at least one example of each facial expression correctly. However, all participants met this criterion, with 42 of the remaining 47 participants (89%) identifying all 6 facial expression pictures correctly.

Likeability ratings: Participants were asked to rate the positive and negative characters for 'likeability' using five items from the Reysen Likability Scale (Reysen, 2005). Initial analysis of the descriptive statistics indicated that the fifth item ('This person is similar to me') received lower agreement scores than the other statements. Mean scores for items 1 to 4 ranged from 53.4 to 58.9 (indicating mild agreement), whereas the mean score for item 5 was 39.4 (indicating disagreement). As item 5 appeared potentially distinct from the other statements, an internal consistency analysis was conducted using R package *psych* (Revelle, 2021). A comparatively low 'corrected item-total correlation'[14] (r = 0.49, whereas items 1 to 4 achieved correlations between 0.76 and 0.83) indicated that the fifth statement did indeed fit poorly with the likeability scale overall. Removal of item 5 also resulted in a small improvement to the scale's internal consistency (new Cronbach's alpha = 0.92). Item 5 was therefore excluded from subsequent analyses,

[14] Correlation (r) between the item of interest and the combined likeability scale score (but with the item of interest removed from the scale).

resulting in a 4-item measure of characters' likeability. The mean score from the remaining 4 items (for each participant) was used in subsequent analyses.

4.3.2. Implicit learning of social cues

Implicit learning from the social cues was predicted to influence participants' likeability ratings, with the positive character viewed as more likeable than the negative character. Shapiro-Wilk normality tests and density plots indicated that participants' likeability ratings for both characters were normally distributed, so a paired-samples t-test was conducted to compare the means. A significant difference in likeability ratings was found ($t_{(46)}$ = 2.18, p = .034), with participants rating the positive character (M = 59.54, SD = 15.6) as more likeable than the character who displayed negative social cues (M = 53.64, SD = 16.5). Because none of the remaining 47 participants were able to describe explicitly any aspect of either character's social cues, it would seem reasonable to conclude that this effect was influenced by implicit learning.

To investigate the relationship further, a new measure of 'likeability difference' (LD) was derived by subtracting a participant's likeability rating of the negative character from their rating of the positive character (LD = positive character rating - negative character rating). A positive number here indicated that the participant liked the positive character more than the negative character, with negative numbers indicating a participant's preference for the negative character.

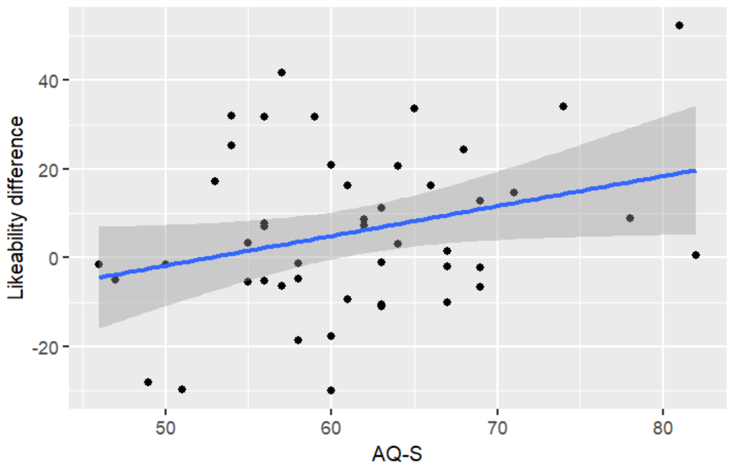
In Macinska's (2019) study, participants were divided, via a median split, into low and high autistic trait groups. Macinska found no significant main effect of 'group' on character likeability ratings. To allow a direct comparison of results, the same median split method was initially employed here, resulting in low- (n = 23, mean AQ-S score = 55) and high-AQ-S (n = 24, mean AQ-S score = 67.46) groups. Similar to Macinska, the current study found no significant main effect of AQ-S group on LD (low-AQ-S mean LD = 2.77, SD = 20.76, high-AQ-S mean LD = 8.9, SD = 15.95, $F_{(1,45)}$ = 1.29, p = .26).

However, by progressing from a 'group differences' analysis to a correlational model, a significant *positive* relationship between LD and AQ-S scores was revealed ($r_{(45)}$ = 0.29, p = .045). A simple linear regression was conducted to further examine the relationship. Overall, the model was found to be a good fit to the data ($F_{(1,45)}$ = 4.25, p = .045, slope coefficient β for AQ-S = 0.67), though an R^2 of 0.09 indicated that just 9% of the variation in LD was attributable to differences in AQ-S. Nevertheless, contrary to predictions, higher levels of self-reported autistic traits (within a TD sample) were associated with increased liking (or disliking) of characters in line with those character's social disposition cues (see **Figure 11**).

Because Study 2 recruited only adult participants, age was not predicted to influence implicit learning of the characters' social dispositions. This position was supported by the results of simple linear regression, which indicated no evidence of a significant relationship between age (in years) and LD ($F_{(1,45)} = 1.4$, $p = .24$).

Figure 11

Correlation between likeability difference and self-reported autistic traits



Note. A small but significant positive correlation was found between AQ-S scores and likeability difference. Higher AQ-S scores (indicating higher levels of autism-like traits) were associated with a greater difference between positive and negative character likeability ratings. The shaded area represents the 95% confidence interval.

4.3.3. Multilevel analyses

Different participants viewed positive and negative characters portrayed by different actors. While participants were allocated randomly to the 4 'actor conditions', physical characteristics of particular actors may have influenced participants' likeability ratings.

If this was the case, likeability ratings for a particular pair of actors may be more similar to each other than likeability ratings between different actor pairings. If so, this 'nesting of data' would violate the assumption required for regression analyses that residual terms are fully independent of one another.

To investigate whether actors did influence likeability ratings, a one-way ANOVA was conducted to compare LD scores by positive actor condition (the actor who displayed positive social cues toward that participant).[15] Results revealed that a significant difference in LD scores did indeed exist between positive actor conditions ($F_{(3,43)} = 4.29$, $p = .01$). Post hoc pairwise t-tests with Bonferroni correction showed that when male actor MG played the positive character, LD ($M = -6.98$, $SD = 13.64$) was significantly lower than when male actor PA ($M = 13.88$, $SD = 16.11$, $p = .029$) or female actor KP ($M = 14.13$, $SD = 18.48$, $p = .026$) displayed positive social cues. No additional LD score differences between other actor conditions reached the level of statistical significance. LD scores, split by positive actor condition, are plotted in **Figure 12**.

Given the positive correlation observed between AQ-S and LD, it was possible that random allocation of lower AQ-S participants to the MG positive actor condition may have resulted in lower LD scores within that condition. However, a further ANOVA confirmed that there were no significant differences in AQ-S score (overall mean = 61.36, $SD = 8.08$) between actor conditions ($F_{(3,43)} = 0.29$, $p = .83$), ruling out this explanation.

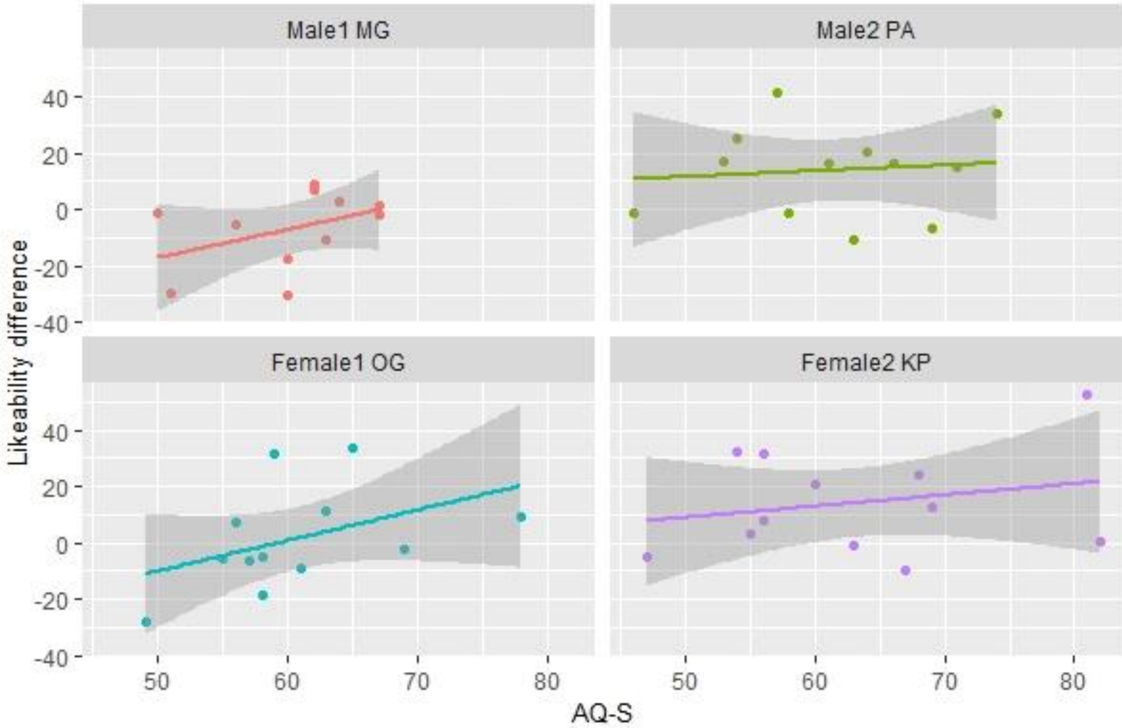
Because LD scores were potentially nested within actor conditions, a multilevel linear model was next fitted to the data. As recommended by Field et al. (2012), the initial goal in multilevel analysis is to establish that sufficient variation exists between contexts (actor conditions in the current study) to warrant this approach. Using R package 'nlme', the data were first fitted to a baseline model (model 1) that predicted LD from just the intercept. Next, data were fitted to a second model (model 2) that allowed regression line intercepts to vary by actor condition. Using maximum-likelihood estimation, the two models could then be compared. Here, a significant change in the negative 2 log-likelihood statistic (change in -2LL = the 'likelihood ratio') would indicate that the second

[15] Every participant viewed positive and negative characters portrayed by two actors of the same sex. Therefore, if male actor MG played the positive character for a participant, the negative character was (by default) played by the other male actor, PA. Aside from the two equivalent female actors who displayed social cues, two further actors (one male, one female) appeared to facilitate catch trials. These 'distractors' never displayed social disposition cues during the learning phase of the task.

(random intercept) model improved data fit, and therefore that significant variation existed between actor conditions.

Figure 12

Influence of individual actors on likeability ratings



Note. Likeability difference (LD), split by positive actor condition. When male actor MG portrayed the positive character, LD was significantly lower than when male actor PA or female actor KP displayed positive social cues. Shaded areas represent 95% confidence intervals.

In the current study, this proved *not* to be the case. An ANOVA that compared -2LL from model 1 (406.73) to -2LL from model 2 (403.34) found the difference to be non-significant (likelihood ratio = 3.39, $p = .066$). Therefore, while the previous t-tests confirmed significant differences in LD scores between certain actor conditions, multilevel analysis found that any disparities in the correlational relationships within the 4 actor conditions did not quite reach the level of statistical significance. The lower mean LD elicited when male actor MG portrayed the positive character may therefore have been an artifact of the high variability in likeability scores and the relatively low number of participants in each actor condition. It is also possible that a genuine 'actor condition effect' may have been masked by the high variability of likeability scores within the 4 actor conditions. This possibility is re-investigated in Study 3.

However, there were three further possibilities for hierarchical (nested) organisation within the data. Firstly, LD scores may have been nested within participant sex. This would have been the case if, for example, female participants gave higher likeability ratings generally than male participants. Secondly, LD scores may have been affected by the sex of the characters that participants viewed. For example, female characters may have been rated as generally more likeable than male characters. Thirdly, LD scores may have been affected by whether or not the participant was the same sex as the characters they were rating (same_sex). This would have been the case if, for example, female participants' likeability ratings of male characters were generally higher than their ratings of female characters. Following the same multilevel modelling procedure described above, separate models were created that allowed the intercept to vary by participant sex (*random_intercept_sex*), character sex (*random_intercept_char_sex*) and 'same_sex' (*random_intercept_samesex*). However, none of these models improved data fit over the baseline model, indicating that there was no significant nesting of data within these variables.[16] Therefore, fitting the data to random intercept models did not contradict (or further develop) the finding of the initial regression analysis that identified a small but significant positive correlation between participants' self-reported autistic traits and LD.

4.3.4. Permutation testing

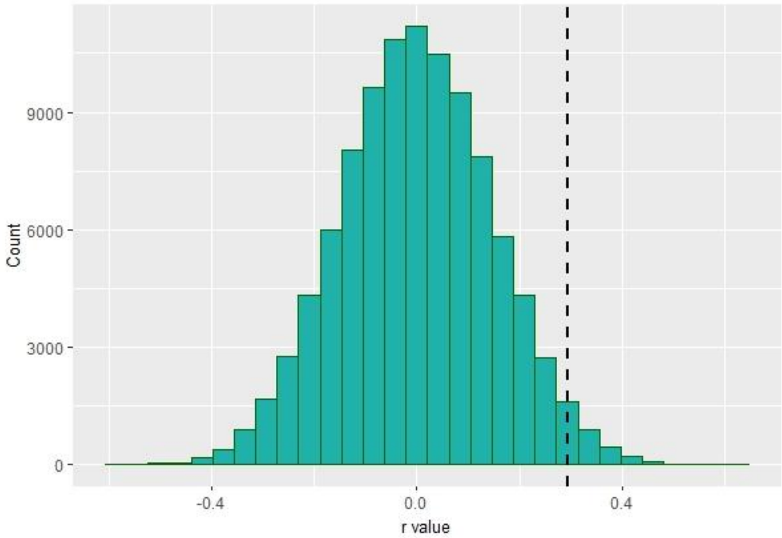
Finally, because the correlation between LD and AQ-S was fairly weak (Pearson's r = 0.29, p = .045) and unexpectedly positive (a negative correlation was predicted), a permutation test was performed to verify the results of the previous analyses. Participants' LD and AQ-S data were permuted 100,000 times, with new correlation coefficients (r) calculated each time. A distribution of new correlation coefficients was generated (see **Figure 13**) from which it was calculated that, from 100,000 permutations, only 2,348 (2.35%) resulted in r values greater than 0.29 (the previously

[16] Likelihood ratios and associated p values for alternative random intercept models: *random_intercept_sex* (likelihood ratio = 5.5e-8, p = 0.9998), *random_intercept_char_sex* (likelihood ratio = 4.1e-8, p = .9998), *random_intercept_samesex* (likelihood ratio = 4e-8, p = .9998).

observed correlation between LD and AQ-S). Therefore, the probability of observing a correlation ≥ 0.29, if there was no relationship between LD and AQ-S in Study 2's participants (the null hypothesis) was calculated as 2,348 / 100,000 = 0.02348. In other words, the permutation test suggested a new one-tailed p-value of .023, supporting the statistically significant correlation found previously between AQ-S and LD.

Figure 13

Permutation test histogram



Note. Histogram showing the distribution of r values following 100,000 permutations of the LD / AQ-S data. The dotted line represents the previously calculated r of 0.29 (p = .045). Just 2,348 of the 100,000 permutations resulted in correlation coefficients greater than 0.29, indicating a new one-tailed p-value of .023.

4.4. Discussion

The current study examined implicit social learning from dynamic facial cues in a TD adult sample. Unlike the previous studies by Hudson et al. (2012) and Macinska (2019), data collection took place online. Participants therefore completed the study in the absence of an experimenter or any laboratory-based controls. 'Disgust' also replaced 'anger' as the facial expression used to convey the negative character's anti-social disposition. Under these conditions, the majority of participants showed no evidence of developing explicit awareness of the learning phase social cues. Nevertheless, the results suggested that social learning had occurred. Shortly following the learning phase (but before 'explicit awareness' questions were presented), participants liked the positive character significantly more than the negative character. Against predictions, the size of this 'likeability difference' related positively to participants' self-reported autistic traits. Therefore, in the current study, TD participants with higher levels of autistic traits seemed the *most* able to learn characters' social dispositions from undetected facial cues.

4.4.1. Was the learning truly <u>implicit</u>?

The current study was designed to investigate *implicit* (rather than explicit) learning. Participants were initially told that the task assessed individual differences in the processing of facial features and emotional facial expressions. Task instructions (for the learning phase) were then to simply react, as quickly as possible, to changes of gaze direction. At no point were participants given reasons to expect follow-up questions related to the learning-phase video clips. Therefore, while it is possible that some participants attempted to learn the characters' social dispositions explicitly, there was no task-inherent reason for them to do so.

After rating the characters for likeability, participants answered questions to gage explicit awareness of the learning phase social cues. Robust, replicable criteria were introduced to identify such awareness, which resulted in the exclusion of 9 of the initial 57 participants (16%). The method chosen to assess explicit awareness was, of course, not without its limitations. For instance, participants were required to write short responses to questions which could otherwise have been skipped, saving participants time and effort. However, almost twice as many 'explicitly aware' participants were identified than in Macinska's study (5 of 54, or 9% of participants), which used very similar learning-phase video stimuli.[17] It seems likely, therefore, that the current study was (at least relatively) stringent in its exclusion of participants for whom learning may have been explicit. As these participants' data were removed before analyses, this

[17] Explicit awareness of learning phase facial cues was not assessed in the study by Hudson et al. (2012). It is also worth noting that, in the current study, 'aware' and 'unaware' participants did not differ significantly on AQ-S score.

study's findings can reasonably be attributed to learning that operated below the level of conscious awareness.

4.4.2. Was the learning truly social?

The current study was designed specifically to investigate implicit acquisition of *social* knowledge. However, actors'/characters' physical appearances (which were unrelated to the social dispositions portrayed throughout the learning phase) may have influenced likeability ratings. For example, when actor 'MG' portrayed the positive character, LD was lower than in certain other actor combinations. However, multilevel analyses revealed no significant nesting of likeability data within 'actor conditions'. In any case, the particular actors portraying the characters were counterbalanced amongst participants. This step was taken to nullify any directional influence of the actors' idiosyncratic qualities on character likeability ratings.

It is also worth remembering that, during the learning phase, the positive and negative characters looked happy and disgusted for precisely the same amount of time. The characters also looked towards, and away from, participants for identical periods. Because these (and other) aspects of the facial cues were carefully controlled, participants' learning could not have been based on simple cues, such as the emotion most frequently displayed. Instead, participants could only have discerned characters' dispositions by integrating the cues successfully. With the actors counterbalanced amongst participants, only if participants had implicitly detected each character's social disposition (i.e., their pro- or anti-social attitudes) should a significant 'likeability difference' have emerged between the two characters.

4.4.3. Interpreting the findings

In this online study, autistic traits were associated with an *increased* ability to learn social information implicitly. This finding is seemingly at odds with previous research which suggested that; a) autistic traits are associated with impaired implicit social learning (Hudson et al., 2012; Macinska, 2019), that b) non-social implicit learning *might* be impaired in autism (Bettoni et al., 2021; Jeste et al., 2015; Klinger & Dawson, 2001) or even that c) implicit learning remains unaffected in autistic individuals (Brown et al., 2010; Foti et al., 2015; Kourkoulou et al., 2012; Mayo & Eigsti, 2012; Obeid et al., 2016).

Because social impairments are a known hallmark of ASD, it would contradict our general understanding of the condition to suggest that increased autistic traits *aid* the real-world implicit acquisition of social knowledge. As mentioned in the preceding chapter, even increased (subclinical) autistic traits in non-autistic samples are associated with *reduced* social awareness and functioning (Sasson et al., 2013; Wainer et al., 2011). Therefore, when attempting to interpret the positive relationship between autistic traits and social learning, the current study's design was examined for elements that may have contributed to this unpredicted finding.

Implicit learning efficiency versus accuracy: In the current study's learning phase, participants viewed 36 'social cue' video clips of both the positive and negative characters. This number of stimuli was chosen to keep learning opportunities broadly in line with previous research. However, by presenting participants with so many repeated social cues, the learning phase might have become unrepresentative of most real-world social exchanges. Because 'naturally occurring' social cues tend to be more varied and fleeting, Lieberman (2000) suggested that implicit learning would need to operate quickly and efficiently if it were to guide social intuition effectively.

The current study found no evidence that the eventual *accuracy* of implicitly derived social judgements related negatively to autistic traits. Instead, when participants were given sufficient social cue input, the opposite relationship was found. While implicit learning accuracy appeared superior (or, at the very least, intact) in higher autistic-trait participants, the same may not necessarily be true for implicit learning *efficiency*. It may have been the case, for example, that high autistic-trait participants required more social learning opportunities than those lower in autistic traits to infer the characters' mental states accurately. Because real-world social exchanges feature relatively few social cue repetitions, reduced implicit learning *efficiency* might help to explain why high autistic traits have been associated with reduced social awareness (Sasson et al., 2013; Wainer et al., 2011).

Reduced efficiency (as opposed to accuracy) might also explain why the predicted negative relationship between autistic traits and implicit social learning was not detected in the current study. A possible limitation of this study was that participants rated the characters for likeability after observing a potentially large surplus of implicit learning opportunities. Theoretically, the lowest autistic trait participants could have learned the characters' social dispositions after just (for example) 15 presentations. Conversely, the participants highest in autistic traits may have required twice as many presentations to fully develop their implicit knowledge of the social cues. Given this possibility, it would be interesting to test whether the positive relationship between autistic traits and LD would be reversed if the number of social cue presentations was reduced significantly. This line of questioning led to the design of Study 3, the details of which are in the following chapter.

Attention to the eyes: People's eye regions provide important information about their mental states (Baron-Cohen et al., 2001a; Peñuelas-Calvo et al., 2019). However, individuals high in autistic traits are known to divert their attention away from the eyes, potentially missing social cues that might otherwise facilitate implicit learning. As in Hudson et al.'s (2012) study, a secondary task required the current study's participants to track characters' gaze directions. Because of this requirement, this study's findings come with an important caveat; the positive correlation demonstrated between autistic traits and implicit social learning was found in TD participants who attended to the characters' eyes almost constantly. 'Gaze avoidance' and 'gaze indifference', which may be more common in higher autistic-trait individuals, were not permitted to limit implicit learning opportunities in the current study. The same, however, may not be true in more natural social settings, or indeed in Macinska's (2019) study, which omitted the gaze monitoring secondary task.

Many studies have demonstrated that non-social implicit learning is unaffected in high-functioning autistic individuals (Brown et al., 2010; Foti et al., 2015; Kourkoulou et al., 2012; Mayo & Eigsti, 2012; Obeid et al., 2016). The current study provides evidence that even *social* implicit learning does not decline as autistic traits increase, as long as participants are required to attend closely to the social cues. It therefore seems possible that attentional factors, such as the autism-related propensity to divert attention from others' eyes (Chevallier et al., 2012; Hadjikhani et al., 2017; Tottenham et al., 2014), may moderate the ability to learn social information implicitly. This hypothesis is further investigated in Study 4 (see Chapter 6).

Attentive readers may have noticed that neither attentional factors, as discussed here, nor the potential surplus of learning-phase opportunities can explain the *positive* correlation found between autistic traits and social learning. Several candidate explanations for this finding are considered later in this thesis, following the results of studies 3 and 4.

4.5. Summary and conclusion

Study 2 investigated whether higher self-reported autistic traits, in a TD adult sample, related to reduced implicit social learning from dynamic facial cues. Studies by Hudson et al. (2012) and Macinska (2019) had demonstrated this relationship using gaze-cueing and perceptual judgment tasks. However, Macinska also found no relationship between participants' autistic traits and the accuracy of their character likeability ratings.

In the current study, participants with varying dimensional autistic traits viewed online presentations of dynamic facial social cues. The majority of the participants showed no evidence of developing explicit awareness of these cues. Nevertheless, participants liked the positive character more than the negative character. Against predictions, the magnitude of this likeability difference correlated positively with participants' autistic traits (AQ-S scores). This finding was supported by multilevel analyses, which ruled out nesting of LD data, including by actor condition and participant sex. Permutation testing also supported the small, but significant, positive correlation found between AQ-S and LD.

Two factors were identified that may have contributed to this finding. Firstly, all participants viewed all 36 presentations of the social cues before rating the characters for likeability. The current study was therefore not able to measure any differences in implicit social learning *efficiency* or establish how these might relate to autistic traits. This question is, however, addressed in Study 3. Secondly, the presence of a gaze monitoring secondary task meant that participants were not able to engage in gaze avoidance- or gaze indifference-related behaviour. It is conceivable that, if the requirement to monitor gaze direction was removed, high-autistic trait participants would be the more likely to divert attention from the characters' eyes, thus missing social cues that would otherwise facilitate social learning. Study 4 was designed to test this hypothesis.

In contrast to the studies by Hudson et al. (2012) and Macinska (2019), Study 2 found no evidence that autistic traits related to impaired implicit social learning. Instead, when participants attended closely to the characters' eyes (and rated characters for likeability immediately after the learning phase), higher self-reported autistic traits were associated with superior learning from the undetected social cues.

Note to the reader: The current study's Discussion section was kept deliberately brief. The current study and the upcoming studies 3 and 4 share many methodological and procedural similarities. It therefore seemed sensible to incorporate a more detailed discussion of the combined findings of these studies into a later section of this thesis. As such, a more comprehensive discussion, which includes an analysis of limitations that pertain to all three studies, can be found in Chapter 6.

Chapter 5. Study 3: Autistic traits and implicit social learning efficiency

5.1. Introduction

Like Macinska (2019), the previous study in this thesis (Study 2) investigated the implicit learning of social information from dynamic human facial cues. The majority of participants (in both studies) were unable to recall details of the social cues but nevertheless rated the pro-social character as more likeable than the anti-social character. The difference between character likeability ratings (LD) was therefore attributed to learning processes which operated below the level of explicit awareness. In Macinska's study, low- and high-autistic-trait participants (differentiated by median split) showed a similar preference for the pro-social character.[18] This outcome, which was replicated in Study 2, suggested that an equivalent amount of implicit social learning had occurred in both sets of participants. However, further analyses of Study 2's data indicated that a significant positive correlation existed between self-reported autistic traits and LD. Therefore, in two studies that used character likeability ratings to assess implicit social learning, neither found evidence that higher autistic traits related to less accurate social judgements.

Participants in both studies viewed a fixed number of social cue video clips (40 of each character in Macinska's study, 36 video clips per character in Study 2) before rating each character for likeability. Therefore, while the eventual *accuracy* of participants' social judgements was assessed, neither study was designed to determine how *efficient* the implicit learning processes were that informed those judgements. Efficiency, in the context of these studies, reflects the ability to gain an accurate (albeit implicit) representation of a characters' social disposition from as few social cue presentations

[18] After Macinska's learning phase, participants judged (in a task separate to character likeability assessment) whether smiling or angry-faced morphed composites of the two characters more closely resembled the positive or negative character. From this task, Macinska found evidence that implicit learning had created a perceptual bias in the low-AQ, but not high-AQ, participants. However, later character likeability ratings revealed that low- and high-AQ participants had learned the characters' social dispositions to a similar extent (see Macinska, 2019, pp. 55-63 for details).

as possible. If, for example, Person A discerned a character's mental state accurately from 10 social cue presentations, whereas Person B required 20 presentations to arrive at a similar level of implicit knowledge, Person A could be considered the more efficient 'implicit social learner'. While implicit learning accuracy appeared to improve as autistic traits increased in Study 2, the opposite may have been true for implicit learning *efficiency*.

There is only one previous study, to the author's knowledge, that has investigated implicit learning efficiency and its relationship to autism. Gordan and Stark (2007) used a serial reaction time (SRT) task to measure non-social ISL in lower-functioning autistic children. Over several training and test sessions, Gordan and Stark demonstrated that the autistic participants *could* gain implicit knowledge of an 8-shape sequence, but that the rate of knowledge acquisition was below that of TD controls. In a second experiment, the same researchers used a 4-shape sequence to reduce the SRT task's cognitive load. With the learning requirements simplified, implicit sequence learning (as evidenced by significant RT differences between sequenced and random stimuli) was found to occur earlier than in the first experiment. Only 7 autistic children took part in testing, so any conclusions drawn from this study are necessarily tentative. However, the study provided initial evidence that autistic children could learn sequences implicitly but required more learning opportunities than TD children to do so. When the sequence to be learned was simplified, the autistic participants required fewer learning opportunities before demonstrating evidence of implicit knowledge.

Though far from providing conclusive proof, both findings seem consistent with the idea that implicit learning may operate less efficiently in children with autism. However, people with ASD are thought to employ explicit learning strategies in situations that would typically elicit implicit processing (Klinger et al., 2007; Zwart et al., 2017, 2018). As discussed in Chapter 1 (see sections 1.5.2 and 1.6), the efficacy of explicit learning strategies depends, in part, on the difficulty of the task. While explicit processing can be effective for learning simple sequences, the additional effort of 'trying to learn' more complex sequences can actually harm learning performance (Finn et al., 2014; Fletcher et al., 2005; Howard & Howard, 2001). It is possible, therefore, to also interpret Gordan and Stark's findings in terms of explicit, rather than implicit, learning. For the autistic participants, the 8-shape sequence may have been sufficiently challenging that it required multiple training sessions to learn explicitly. The simpler 4-shape sequence, which may have been far more conducive to explicit learning, was learned more quickly. However, Gordan and Stark (2007) did not attempt to evaluate participants' explicit awareness of the sequences. It is therefore difficult to ascertain whether disparate cognitive strategies subserved learning in the two participant groups.

5.1.1. Study 3 rationale and predictions

If social knowledge is acquired implicitly (Lieberman, 2000), one might predict a positive relationship between implicit learning and social functioning. Increased autistic traits relate to diminished social functioning and awareness (Sasson et al., 2013; Wainer et al., 2011). It would therefore seem worthwhile to investigate whether this relationship could be mediated by autistic trait-related differences in implicit social learning efficiency. If autistic traits *do* relate negatively to implicit learning efficiency, people low in autistic traits should be capable of inferring others' mental states accurately from even a few fleeting social cues. People higher in autistic traits, however, might require more learning opportunities before gaining an accurate implicit knowledge of others' attitudes. Study 3 investigates this possibility.

Using a near-identical learning phase to Study 2, two characters again displayed opposite social dispositions towards the participant via specific combinations of facial expressions and gaze directions. Study 2 demonstrated that 36 presentations of these social cues elicited significantly differing character likeability ratings, the magnitude of which correlated *positively* with autistic traits. The current study tested whether this relationship would be altered by presenting fewer social learning opportunities. Participants were therefore presented with either 24 or 12 presentations of the social cue video clips before they rated the characters for likeability. Because implicit social learning should, theoretically, operate quickly and efficiently, participants were still predicted to rate the positive character as the more likeable in both of the new 'cue conditions'. However, for participants who viewed 24 social cue presentations, it was predicted that Study 2's positive correlation between autistic traits and LD would be eliminated, or possibly reversed. For participants who were exposed to the fewest social learning opportunities (12 cue presentations), self-reported autistic traits were predicted to correlate *negatively* with the study's measure of learning (LD).

5.2. Method

5.2.1. Participants

Approval for this study was granted by Nottingham Trent University's College Research Ethics Committee. All participants provided consent via an online form before taking part in the study. Because of ongoing concerns about coronavirus infection rates in the UK, and to maintain consistency with Study 2, all testing was completed online. 128 participants (24 male and 104 female, aged 18 to 51 years old, mean age = 22, SD = 5.01) took part in testing, all of whom were recruited via social media channels or via Nottingham Trent University's Psychology Research Participation Scheme. None of the participants had taken part in Study 2.

2 participants (1 male and 1 female) reported that they had previously received an ASD diagnosis. These diagnoses were not verified by the researcher and data from these 2 participants were combined with other participants' data in later analyses. Participants were incentivised to take part in the research with the chance to win a first prize of £100 in Amazon vouchers, or one of two smaller prizes of £20 in Amazon vouchers. NTU psychology students who completed the online study had the option to choose between the prize draw and receiving research participation scheme credits.

5.2.2. Task stimuli

Study 3 used identical video stimuli to Study 2. Please see section 4.2.2. for details. As before, an actor was portrayed as having a positive disposition by combining an initial expression of joy with gaze directed forward (towards the participant). This configuration then transitioned to an expression of disgust during which the actor's eyes were averted. To portray an actor as having a negative disposition toward the viewer, an initial expression of disgust was combined with gaze directed forward, which then transitioned to an expression of joy while the actor looked away to the side. As in Study 2, each participant saw three actors of the same sex. One actor consistently displayed positive disposition cues, a second actor always displayed negative cues and a third actor appeared as a neutral distractor (and facilitator of catch trials).

5.2.3. Task procedure

The procedure for the current study was near-identical to Study 2. As before, testing took place entirely online, using a computer of the participant's choice. Participants were assigned to one of two learning phase conditions (at random), which differed only in the number of video clips that participants viewed.

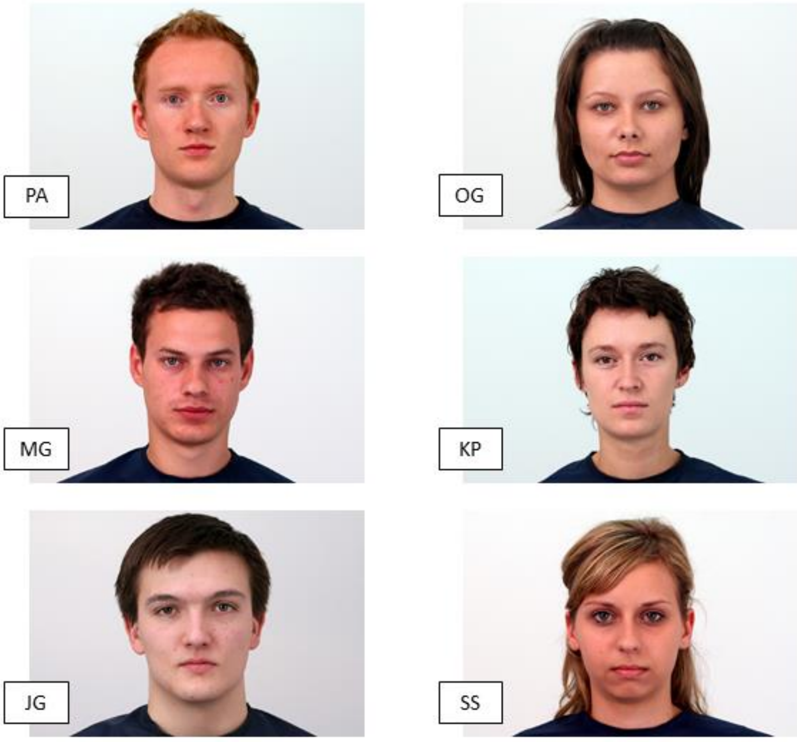
Learning phase: In the 'short exposure' condition, participants viewed 12 video clips of the positive disposition character (6 played forward and 6 in reverse) and 12 of the negative disposition character (again, 6 played forward and 6 in reverse). Clips were played in pseudo-random order intermixed with 8 video clips of the neutral distractor character. Half of the neutral character's clips featured eye movement, while half featured no change of gaze direction and acted as catch trials.

Throughout the presentation of stimuli (32 video clips in total), no character appeared twice in succession. Participants viewed videos featuring only female or only male actors (a condition assigned at random). As was the case in Study 2, female actors OG and KP portrayed positive or negative dispositions (randomised between participants) while model SS always featured as the neutral distractor. For participants viewing male actor video clips, PA and MG portrayed positive or negative dispositions (again, randomised between participants) with JG acting as the neutral distractor (see **Figure 14**).

Participants in the 'medium exposure' condition viewed 64 video clips in total, which included 24 clips of the positive disposition character and 24 clips of the negative. The previous study (Study 2) effectively provided data for the 'long exposure' condition, during which participants viewed 96 video clips (36 for both positive and negative disposition characters). All three exposure conditions featured an identical ratio of positive and negative disposition character videos, neutral character videos featuring eye movement and neutral character catch trails (see **Table 4**).

Figure 14

Actors that portrayed the characters during the learning phase



Note. Just as in Study 2, male actors PA and MG and female actors OG and KP portrayed the positive and negative characters. Actors JG and SS appeared as neutral distractors and to facilitate catch trials. All actors are pictured here with neutral facial expressions.

Test phase: The test phase for Study 3 was identical to Study 2. It is therefore summarised here only briefly. Immediately following the learning phase, participants were asked how many different individual actors appeared in the video clips (correct answer: 3). This was to establish that participants had paid sufficient attention to the stimuli and could differentiate between the faces of the actors featured. Participants were then asked to rate the positive and negative disposition characters (in randomised order) for 'likeability' using items from the longer Reysen Likability Scale (Reysen, 2005).

Table 4

Learning-phase stimuli - short, medium and long exposure conditions

Exposure condition	Stimulus type (character's portrayed disposition toward participant)						
	Positive (fwd)	Positive (rev)	Negative (fwd)	Negative (rev)	Neutral / distractor (with eye motion)	Neutral / distractor (no eye motion - catch trial)	Total
Short	6	6	6	6	4	4	32
Medium	12	12	12	12	8	8	64
Long (Study 2)	18	18	18	18	12	12	96

Note. Breakdown of video stimuli presented to participants. Each participant saw 3 actors of the same sex. One actor consistently displayed positive disposition cues, one actor consistently displayed negative disposition cues while a third distractor character remained neutral throughout the trials. Participants always viewed an equal number of video clips of the positive and negative characters, exactly half of which were played forward (fwd) and half of which were played in reverse (rev).

Next, participants' explicit knowledge of the characters' social cues was assessed. They were shown an image of the neutral character and asked: 'In videos featuring this person, did you notice any patterns in their gaze direction and facial expressions?'. If the participant answered 'yes', they were asked to briefly describe any patterns that they had observed. This process was repeated for the positive and negative disposition characters. Participants were then shown 6 randomised still images of the positive and negative character actors displaying 'disgust', 'joy' and 'neutral' facial expressions. For each image, participants were asked to select the word that best described the actor's emotion. Finally, participants completed the AQ-S (Hoekstra et al., 2011), a 28-item version of the longer AQ (Baron-Cohen et al., 2001b) which measures the degree to which adults with normal intelligence have traits associated with autism.

5.3. Results

5.3.1. Data reduction

For consistency (and to allow the pooling of data from studies 2 and 3) the data reduction criteria from Study 2 were retained. Please see section 2.3.2 for full descriptions of the data reduction procedures. What follows is a summary of the data reduction outcomes solely from Study 3.

Inattention to stimuli: Throughout the learning phase, participants faced catch trials in which the neutral character's gaze direction did not change. Participants responded correctly to catch trials by *not* pressing the space bar. Participants' data were removed ahead of further analysis if they responded correctly to fewer than half of the catch trials. 5 participants (3.9% of the original 128 participants) were excluded for this reason. Just as in Study 2, no participants were excluded for making response errors on more than 20% of non-catch trials.

Face differentiation: Just as in Study 2, all participants stated that they had seen *at least* three individual people in the video clips. Therefore, no participants were excluded for failing to differentiate between the faces of the characters.

Explicit awareness: Participants were asked to write brief descriptions of any patterns in gaze direction and facial expression that they had observed. Participants were scored as having developed explicit awareness if they unambiguously referred to at least one 'half' of a character's social cue contingencies (for example, stating that the negative character grimaced while looking forward *and*/*or* that the negative character smiled while looking to the side). 6 of the remaining 123 participants (4.9%) showed evidence of developing explicit awareness for *both* positive *and* negative characters. A further 24 participants demonstrated explicit awareness of *either* the positive or negative character's cues. Of the 30 participants who showed evidence of explicit awareness, 17 were from the medium exposure condition and 13 were from the short exposure condition. An unpaired two-samples t-test was conducted to examine whether participants' self-reported autistic traits (AQ-S scores) were related to their development of explicit awareness. There was no significant difference in AQ-S scores ($t_{(125)}$ = 0.93, p = .36) between explicitly aware participants (M = 62.21, SD = 9.08) and those who remained unaware of the social disposition cues (M = 60.33, SD = 9.84). The data from all 30 explicitly aware participants (23.4% of the original 128 participants) were excluded from subsequent analyses.

Facial expression identification: Participants would have been excluded if they were unable to identify at least one example of a 'disgust', 'joy' and 'neutral' facial expression correctly. All participants surpassed this threshold, with 80 of the remaining 93 participants (86%) identifying all 6 facial expression pictures correctly. After the exposure criteria had been applied, 52 participants remained from the short exposure condition (12 video clips) and 41 from the medium exposure condition (24 video clips).

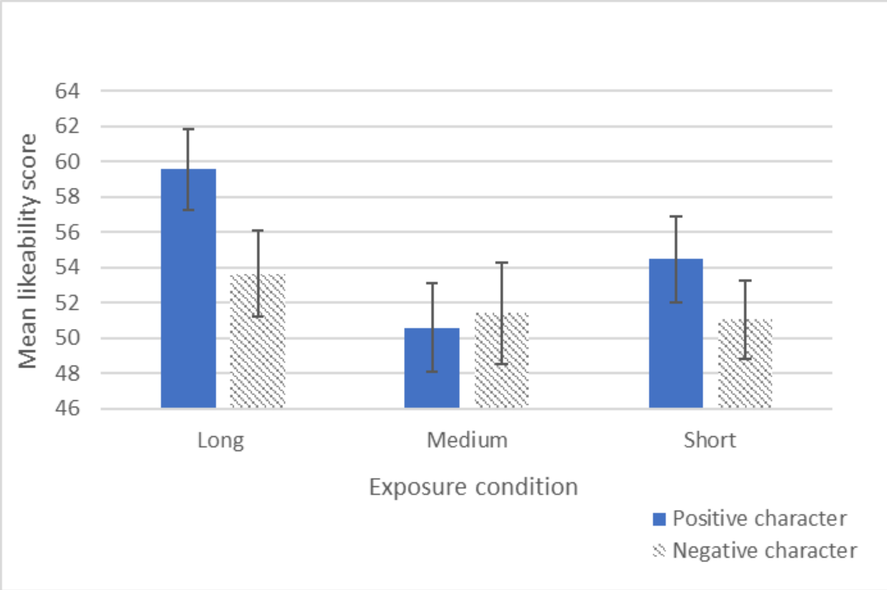
Likeability ratings: In Study 2, the fifth Reysen Likability Scale item ('This person is similar to me') was found to fit poorly with the scale overall (see section 4.3.1). To be consistent with Study 2, a reduced 4-item version of the scale was again used to quantify likeability of the pro- and anti-social characters. Each participant's mean scores from the 4 items were used in the following analyses.

5.3.2. Implicit learning from social cues

Study 2 found that, in the long exposure condition (36 presentations of each character), implicit learning from the social cues influenced participants' likeability ratings, with the positive character (mean= 59.5, SD = 15.6) viewed as significantly more likeable than the negative character (M = 53.6, SD = 16.5, $t_{(46)}$ = 2.18, p = .034). However, this result was not replicated in the medium and short exposure conditions in Study 3 (see **Figure 15**). After checking that likeability ratings for both characters were approximately normally distributed, paired-samples t-tests revealed no significant differences between character likeability ratings in either the medium ($t_{(40)}$ = -0.25, p = .8) or short exposure ($t_{(51)}$ = 1.33, p = .19) conditions.

Figure 15

Character likeability scores, split by learning phase exposure condition



Note. Likeability ratings were provided via an unmarked 100-point sliding scale, where a score of 50 (the slider's midpoint and starting position) indicated a neutral opinion towards a character. There was a significant difference in likeability ratings between the positive and negative character in the long exposure condition (data from Study 2, 36 presentations of each character's video clips). The expected preference for the positive character was not present in the medium exposure condition (24 presentations) and the difference in likeability ratings between positive and negative characters was not significant in the short exposure condition (12 presentations). Bars represent SEM.

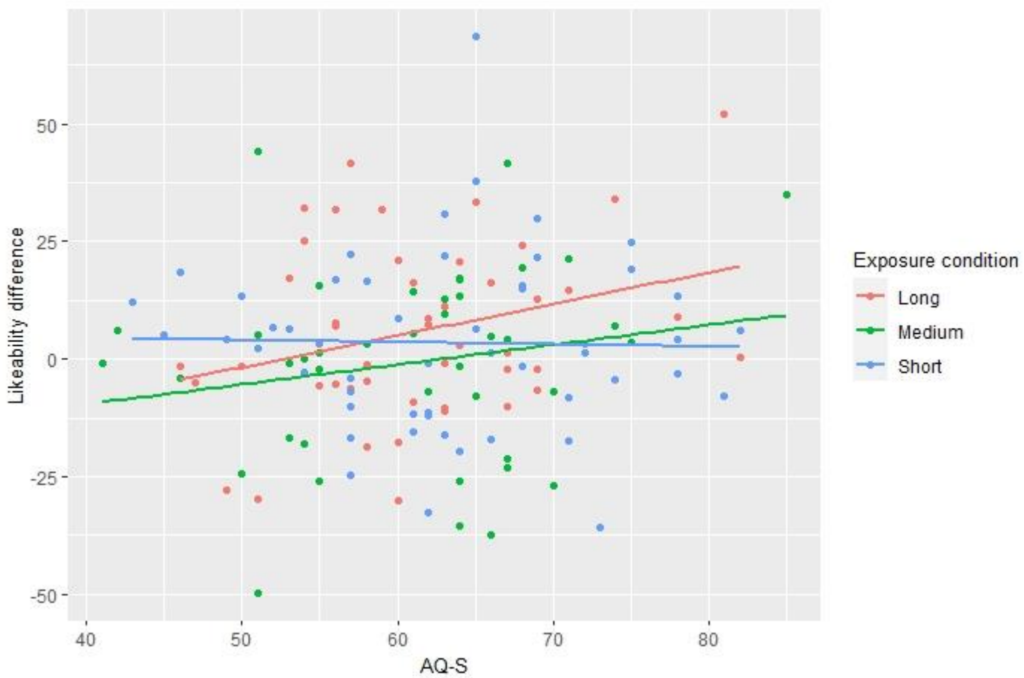
5.3.3. Likeability difference and autistic traits

Participants' dimensional autistic traits were assessed using the AQ-S (Hoekstra et al., 2011). To check that the current study's unsupervised online presentation of items had not reduced the scale's reliability, internal consistency was assessed by calculating Cronbach's alpha (α). After analysing AQ-S data from all Study 2 and 3 participants, internal consistency (α = 0.79) was directly in line with Hoekstra et al.'s own findings (α between 0.77 and 0.86), indicating that the scale's 'acceptable to good internal consistency' (Hoekstra et al., 2011) had been retained.

To investigate whether AQ-S total score was related to implicit social learning, LD was calculated by subtracting a participant's likeability rating of the negative character from their rating of the positive character. A positive LD indicated that the participant liked the positive character more than the negative character, with a negative LD indicating a participant's preference for the negative character. In Study 2 (the long exposure condition), LD and AQ-S were significantly positively correlated (Pearson's r = 0.29). Simple linear regressions were conducted to see whether a similar relationship was present in the medium and short exposure conditions (see **Figure 16** for a plot of LD data from all three exposure conditions).

Figure 16

Correlations between self-reported autistic traits and LD from all three exposure conditions



Note. A small but significant positive correlation was found between AQ-S scores and LD in the long exposure condition (data from Study 2). Higher AQ-S scores (self-reported autistic traits) were associated with a greater difference between positive and negative character likeability ratings. No significant correlational relationship was evident in either the medium or short exposure conditions.

In the medium exposure condition, AQ-S did not significantly predict LD ($F_{(1,39)}$ = 1.4, p = .24). Similarly, in the short exposure condition, there was no significant relationship between AQ-S and LD ($F_{(1,50)}$ = 0.03, p = .87). A linear regression performed on the combined data from all 3 exposure conditions also revealed no significant relationship between AQ-S and LD ($F_{(1,138)}$ = 2.77, p = .098). Furthermore, an ANOVA found no significant differences in LD scores between the 3 exposure conditions ($F_{(2,137)}$ = 1.37, p = .26).

Because participants were assigned to exposure conditions at random, self-reported autistic traits were not expected to differ significantly between exposure conditions. An ANOVA confirmed this to be the case, with results revealing no significant differences in AQ-S total scores ($F_{(2,137)}$ = 1.37, p = .26) between the long (M = 61.36, SD = 8.08), medium (M = 60.88, SD = 9.1) and short (M = 63.19, SD = 9.43) exposure conditions.

Since Study 3 (like Study 2) recruited only adult participants, age was not predicted to significantly influence implicit learning of the characters' social dispositions. This prediction was supported by the results of a further linear regression, which indicated no significant relationship between age (in years) and LD ($F_{(1,45)}$ = 1.4, p = .24) when data from all 3 exposure conditions were fitted to the model.

5.3.4. AQ-S subscale analysis

In the above analyses, AQ-S total score was used to quantify participants' self-reported autistic traits. However, as mentioned in Chapter 3, Hoekstra et al. (2011) reported that the AQ-S's 28 items loaded onto two separate, higher-order factors: broad difficulties in social functioning (23 items) and fascination for numbers/patterns (5 items). One might predict that reduced implicit social learning would relate strongly to 'broad difficulties in social functioning', but less so to 'fascination for numbers/patterns'. To investigate whether LD was related to either of these separate factors (rather than AQ-S total), correlations were calculated using participants' separate scores from the 'social functioning' and 'numbers/patterns' sub-scales. No correlations between LD and the sub-scale scores were found to be statistically significant (p < .05) when analysed at exposure condition levels (36, 24 or 12 presentations) or across all 3 exposure conditions. Only the correlation between 'numbers/patterns' and LD in the long exposure condition (36 presentations) approached the level of statistical significance

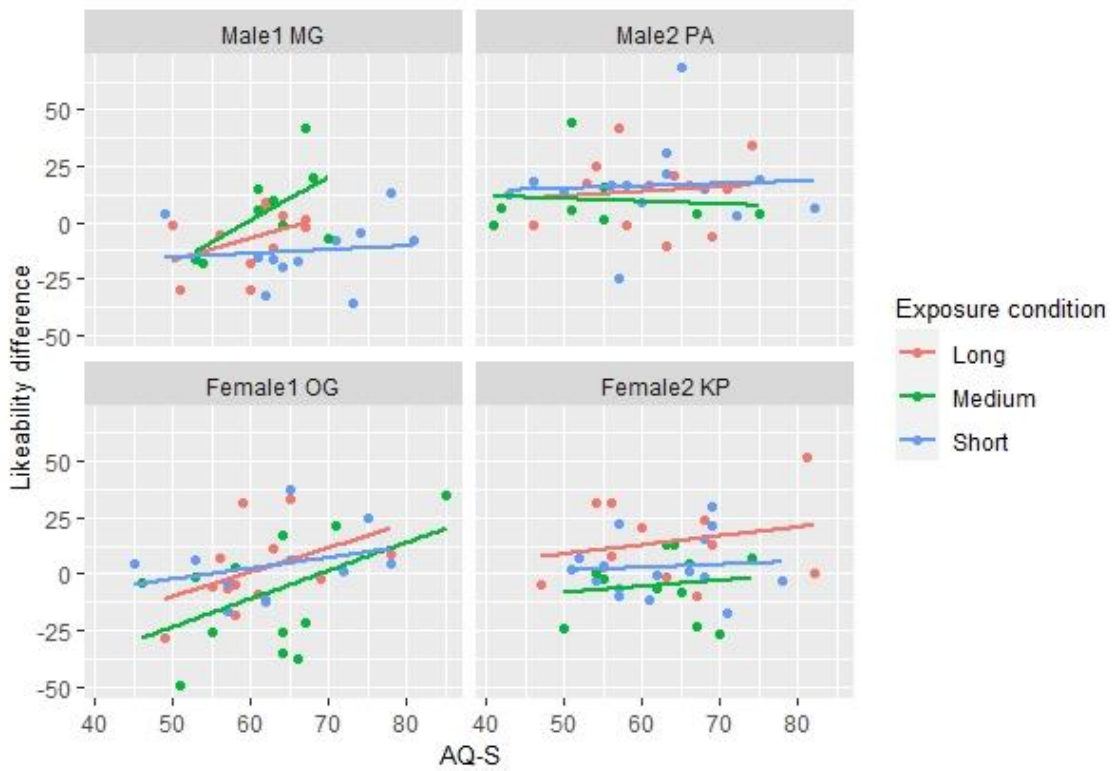
(Pearson's r = 0.28, $t_{(45)} = 1.94$, $p = .058$). Therefore, the only significant AQ-S-related correlation remained the one found between LD and AQ-S total score in the long exposure condition.

5.3.5. Multilevel analysis

As identified in Study 2, task data had the potential to be hierarchically organised (or 'nested') in several different ways. Visual inspection of the data (see **Figure 17**) again suggested that likeability scores may have been nested within actor conditions (i.e., the particular actors portraying the positive and negative characters may have influenced likeability ratings). Likeability scores may also have been nested within participant sex (for example, if male participants tended to give higher likeability ratings than females), character sex, or may have been influenced by whether or not the participant was the same sex as the characters they were rating (a condition referred to here as 'same_sex').

Figure 17

Correlations between AQ-S total score and LD, split by actor condition



Note. Visual inspection of the data indicated potential nesting of the data by actor condition. In particular, LD appeared to be lower (and more likely to be negative) when actor MG portrayed the positive character (Male1 MG) than when actor PA portrayed the positive character (Male2 PA).

Preliminary analyses using simple regression models indicated that a significant likeability score difference existed between positive and negative characters in the long exposure condition, and that this difference correlated positively with AQ-S. No such relationships were found in the medium and short exposure conditions. However, if data *were* nested in any of the ways described, this would violate an important assumption of correlational analyses that residual terms are independent; a violation which could have important consequences for the validity of any conclusions drawn. Therefore, the next step was to fit the data from studies 2 and 3 to a model that could identify and analyse any hierarchical organisation present.

Study 3 introduced a fourth source of potential data nesting in the form of exposure conditions (the number of social disposition video clips that participants viewed). Exposure conditions were, of course, an experimental manipulation, rather than an 'incidental' (or potentially confounding) variable. However, differences in participant performance between conditions could still be modelled via multilevel analysis.

Following the procedure recommended by Field et al. (2012), the data from all exposure conditions were first fitted to a baseline model (*intercept_only*) that predicted LD from just the intercept. Data were then fitted to a second model (*random_intercept_actor*) that allowed regression line intercepts to vary by the actor who portrayed the positive character. Using maximum-likelihood estimation, the two models could then be compared. The 'likelihood ratio' test and its associated significance ($p = .002$, in this case) indicated that the *random_intercept_actor* model fitted the data more accurately than the baseline model, and therefore that significant variation existed between actor conditions. This result differed from that of Study 2, where the same procedure identified no significant differences between actor conditions.

The above procedure was repeated, creating separate models that allowed the intercept to vary by participant sex (*random_intercept_sex*), the sex of the stimulus characters (*random_intercept_char_sex*), 'same_sex' (*random_intercept_samesex*) and exposure condition (*random_intercept_exposures*). However, none of these models improved data fit over the baseline model, indicating that there was no significant nesting of data within these variables.[19]

Using *random_intercept_actor* as the new baseline model, with intercepts now being allowed to vary by actor condition, the model was developed by adding predictor variables one by one. Following each addition, a likelihood ratio test was conducted to determine if adding the new variable significantly improved data fit. As the only two variables initially predicted to affect LD, AQ-S was added first (*addAQS*), followed by exposure condition (*addExposure*). As can be seen in **Table 5**, adding AQ-S as a predictor significantly improved the fit of the model (p = .021), whereas adding 'exposures' did not (p = .31).

Table 5

Construction of the multilevel model

Model	Test (models compared)	Likelihood ratio	p-value
1. *intercept_only*			
2. *random_intercept_actor*	1 versus 2	9.53	.002*
3. *addAQS*	2 versus 3	5.32	.021*
4. *addExposure*	3 versus 4	1.05	.307
5. *add_AQSxExposure_inter*	4 versus 5	1.78	.182
6. *add_randomslope*	5 versus 6	1.82	.402

Note. Allowing intercepts to vary by positive actor condition (*random_intercept_actor*) and the addition of AQ-S as a predictor (*addAQS*) both improved the data fit of the model, as determined by likelihood ratio tests (L.Ratio) and their associated probability values (p-value). Asterisks indicate statistically significant test outcomes (p < .05).

Because autistic traits (AQ-S) were predicted to have had a different effect on LD at the different levels of exposure condition, an interaction term (AQ-S x exposures) was then

[19] Likelihood ratios and associated p values for alternative random intercept models: *random_intercept_sex* (likelihood ratio = 1.9e-7, p = .9996), *random_intercept_char_sex* (likelihood ratio = 1.7e-7, p = .9997), *random_intercept_samesex* (likelihood ratio = 1.6e-7, p = .9997), random_intercept_exposures (likelihood ratio = 1.3e-7, p = .9997).

added to the model (*add_AQSxExposure_inter*). However, this addition also did not improve the model (p = .18). Until this stage, LD for each participant was predicted by 'random intercepts' that varied across actor conditions, but by fixed regression slopes. As a final step, 'random slopes' were introduced by allowing the effect of AQ-S (i.e., the slope coefficient of the regression line) to vary across actor conditions (*add_randomslope*). Again, this addition resulted in no significant improvement to the data fit of the model (p = .4).

Having constructed the multilevel model, just two elements were found to improve data fit: random intercepts for actor conditions and the introduction of AQ-S as a fixed-effect predictor variable. Reverting to the version of the model with just these two elements in place (*addAQS*), inspection of the parameters showed that AQ-S total now significantly predicted LD ($t_{(135)} = 2.3$, $p = .022$) with a fixed slope coefficient of 0.4. Like the regression analysis from the long exposure condition (Study 2), the new coefficient indicated a small but positive correlation between AQ-S and LD, once intercepts were allowed to vary by actor condition.

5.4. Discussion

Study 3 extended the reach of Study 2 by examining how fewer exposures to dynamic facial cues affected implicit learning of social information. As in Study 2, TD participants with varying autistic traits were required, by a secondary task, to monitor the characters' eye regions throughout the learning phase. This task was retained to reduce the potential effects of gaze avoidance or gaze indifference on social learning in this experimental setting.

In the long exposure condition (data from Study 2), implicit learning from the social cues resulted in participants liking the positive character more than the negative character. However, in both the medium and short exposure conditions, no significant differences in character likeability ratings were found. Contrary to predictions, 24 and 12 social cue presentations appeared not to foster sufficient implicit knowledge of the characters' social dispositions to influence participants' likeability judgements. However, this finding did not account for individual variability in implicit learning performance which may have related to dimensional autistic traits. It was therefore important to further examine the correlational relationship between AQ-S and LD, despite the initial null finding.

In the long exposure condition (36 cue presentations), a significant positive correlation was found between AQ-S and LD. Based on the hypothesis that autistic traits may relate negatively to implicit learning *efficiency*, fewer presentations of the social cues were predicted to nullify or reverse the correlation found previously. No evidence of this trend was found, with AQ-S not predictive of LD in either the medium or short exposure conditions. However, multilevel analyses again revealed a *positive* correlation between AQ-S and LD across all 3 exposure conditions, once intercepts were allowed to vary by actor condition. Study 3 therefore found no evidence that autistic traits related to impaired implicit social learning accuracy or efficiency. Instead, combined data from studies 2 and 3 again indicated that higher self-reported autistic traits were associated with more accurate learning from undetected social cues.

To the author's knowledge, no previous research has demonstrated a positive relationship between autistic traits and any form of social learning. Instead, higher autistic traits have long been associated with *reduced* social awareness and functioning, even in non-autistic samples (Sasson et al., 2013; Wainer et al., 2011). There is, however, one theoretical model of autistic perception that *could* be compatible with the current studies' findings. The learning rate 'imbalance hypothesis' (Chrysaitis & Seriès, 2022) suggests that newly acquired information may affect perception to a greater extent in autistic than non-autistic individuals. This theory is discussed in detail in the following section.

5.4.1. Bayesian inference and the 'imbalance hypothesis' of autistic cognition

Bayesian inference, in a purely data analytical context, applies Bayes' theorem to evaluate hypotheses as more data become available. In simple terms, newly collected information (the 'likelihood distribution') is compared to an existing bank of data (the 'prior distribution') to produce our most accurate interpretation of all data available (the 'posterior distribution'). From the posterior distribution, we can infer the probability that a given hypothesis is correct (Dienes, 2014).

It has been proposed that human perception and belief formation rely on a process similar to Bayesian inference (Gregory, 1980; Kersten et al., 2004; Knill & Richards, 1996; Norris et al., 2016; Sohn & Narain, 2021). Potentially ambiguous sensory inputs (newly collected 'data') are implicitly processed in a bottom-up manner by the brain. At the same time, implicit top-down processing allows the incoming data to be interpreted using our prior knowledge of the real-world origins of similar sensory input.

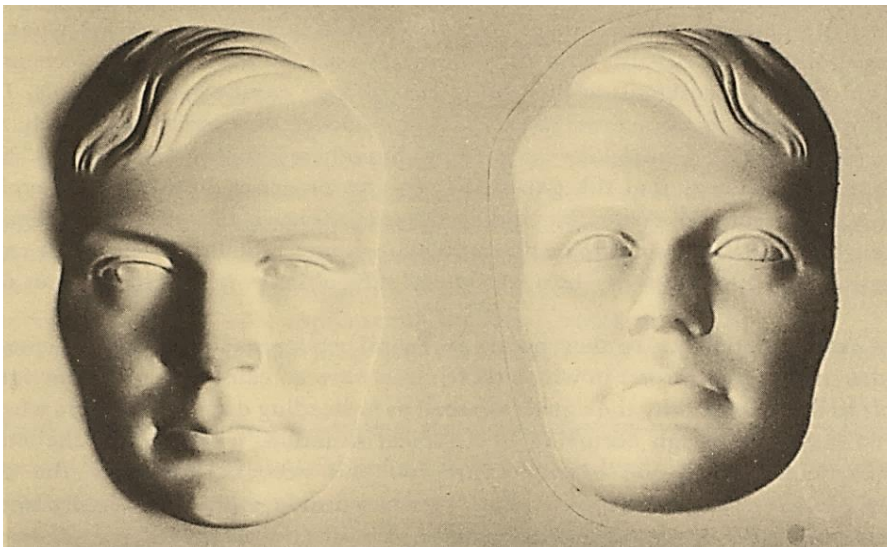
Take, for example, the process of face perception. When light reflected from a person's face activates the photoreceptors in our eyes, the resulting neural signals are sent to the brain for interpretation. For our brains to produce an accurate percept of the face, prior knowledge may be used to interpret any ambiguity in the sensory input. We know implicitly, for example, that faces are generally convex (Gregory, 1980) and that objects are usually illuminated from above (Croydon et al., 2017). This prior knowledge is thought to influence our interpretation of shading and shapes, producing a (potentially) accurate hypothesis that we are indeed viewing a face. Because the brain receives an ongoing stream of sensory data, hypotheses about the world are continually being updated, with the most probable hypothesis representing our conscious perception or belief (see Palmer et al., 2017 for a more detailed account of this process).

The hollow face illusion (Gregory, 1980) is a good illustration of how this unconscious inferential process can go awry (see **Figure 18**). When presented with a concave (hollow) mould of a face, illuminated from below, most participants perceive it as a 'normal' convex face lit from above. A strong prior belief that faces project outwards (developed through years of experience) is enough to override the somewhat ambiguous stereoscopic counter-information within the visual signal. The perception of an outward-projecting face (which in this case is inaccurate) therefore reflects an implicit Bayesian calculation that places the 'convex face hypothesis' as more probable than a 'concave face hypothesis'.

When calculating the probabilities that alternative hypotheses are correct, the relative weight assigned to new data and to 'priors' is thought to vary with the estimated precision (reliability/unambiguousness) of the two information sources. The weighting term is often referred to as the 'learning rate' (Palmer et al., 2017). When newly acquired information dominates the inferred belief, the learning rate is considered high. For example, for someone who believed that all sheep are white, seeing a black sheep might induce a high learning rate that overrides (and triggers an update to) their 'white sheep' prior. Conversely, when prior knowledge has the greater influence on beliefs (as illustrated in the 'hollow face illusion' example), the learning rate is considered low.

Figure 18

The hollow face illusion



Note. The face on the right is a concave mould of the face on the left. However, both faces are usually perceived as convex (nose projecting towards the camera) by viewers.

Either through priors being underweighted (Pellicano & Burr, 2012), or through new input being overweighted (Brock, 2012), it has been suggested that learning rates may be atypically high in autistic individuals (Lawson et al., 2014; Van de Cruys et al., 2014). The 'imbalance hypothesis' (Chrysaitis & Seriès, 2022) therefore proposes that autistic cognition generally favours the bottom-up processing of new information at the expense of the top-down influence of prior knowledge. Extrapolations of the imbalance hypothesis have been used to interpret a variety of autism-related phenomena (Chrysaitis & Seriès, 2022; Palmer et al., 2017). Pellicano and Burr (2012), for example, suggested that the upweighting of sensory input in autistic individuals may explain their commonly reported hypersensitivity to sound (Gomes et al., 2008; Williams et al., 2021), while the relatively decreased influence of priors could explain autistic participants' reduced susceptibility to certain illusions (Chouinard et al., 2016; Happé, 1996). Atypical processing of prior knowledge and sensory inputs may also contribute to predictive impairments (Courchesne & Allen, 1997; Sinha et al., 2014; Van de Cruys et al., 2014), which may render (particularly unfamiliar) environments chaotic and stressful to many autistic individuals.

Study 2 and 3's findings could also be interpreted in terms of the imbalance hypothesis. If increased autistic traits relate to higher learning rates, the newly acquired social information (from facial cues in the learning phase) would be given more weight in the high AQ-S participants' perceptions of the characters. The imbalance hypothesis is therefore potentially consistent with the positive relationship found between AQ-S and LD. However, wider experimental evidence for an autism-related learning rate imbalance remains inconclusive.

Chrysaitis and Seriès (2022) conducted a systematic review of research that investigated the Bayesian account of autism. In total, 92 experiments (from 83 published studies) yielded outcomes that were clearly interpretable in terms of likelihood (newly acquired information) versus prior weighting. Some of the experiments included in the review compared the performance of autistic and control participants, while others investigated the relationship between autistic traits and learning rates. Within each category, some experiments assessed the relative influence of pre-existing priors (for example the 'illumination from above' prior discussed previously), while others induced new priors (either explicitly or implicitly) as part of their experimental design. Overall, the majority of experimental results did *not* support the imbalance hypothesis. Just 37% of the experimental outcomes indicated autism-related learning rate differences in line with Bayesian account predictions. An autism-related learning rate imbalance is therefore only partially supported by evidence, making it problematic to confidently interpret Study 2 and 3's results in terms of this model.

Indeed, it is possible to interpret the positive AQ-S/LD correlation (found in studies 2 and 3) in a way that directly contradicts the imbalance hypothesis. As mentioned above, many of the studies that investigated the Bayesian model of autism did so by inducing new priors as part of their experimental design. For example, in Maurer and colleagues' (2018) study (which was included in Chrysaitis and Seriès' systematic review), participants played a co-operative, trust-based investment game with 'virtual partners'.

Before the game began, the researchers established positive or negative reputational priors for these 'partners' by describing their lifestyles as either morally praiseworthy or objectionable. Maurer et al. found that both TD and autistic participants initially risked higher investments with the 'morally trustworthy' partners. However, while TD participants quickly used in-game investment feedback (the likelihood distribution) to alter their tactics and maximise returns, autistic participants' choices continued to be influenced by the priors for the duration of the game. Maurer et al. concluded that autistic participants assigned a greater weight to the recently established reputational priors, which then remained resistant to revisions based on newly acquired information. This interpretation is consistent with a lower (not higher) learning rate being associated with autism.

A similar conclusion could be drawn for studies 2 and 3. One could argue that the learning phase did not, as initially suggested, provide the new information (likelihood distribution) that was weighted more heavily in the high AQ-S participants' perceptions. Similar to Maurer et al. (2018), the learning-phase stimuli may, instead, have established new 'social disposition priors' for the positive and negative characters; priors that were weighted more heavily for higher AQ-S participants. Taking this view, it would follow that the positive relationship found between LD and AQ-S was in *opposition* to the imbalance hypothesis, rather than providing evidence in its favour.

With no evidence-supported reason to choose one interpretation over the other, the imbalance hypothesis appears unfalsifiable in the context of the current studies. Indeed, versions of the imbalance hypothesis have been used previously to interpret apparently contradictory findings (see Palmer et al., 2017 for a review). This is therefore not the first time that Bayesian models of autism have faced falsifiability concerns. Especially as current evidence for an autism-related learning rate imbalance is, at best, inconsistent (Chrysaitis & Seriès, 2022), it remains unclear whether a Bayesian interpretation of the current studies' results should be considered at all. Because of this uncertainty, several further candidate explanations for the positive AQ-S/LD correlation are explored in the Discussion section of Chapter 6.

5.4.2. Summary and conclusion

Study 3 extended the reach of Study 2 by investigating whether increased autistic traits, in TD participants, were associated with reduced implicit social learning efficiency. Combined data from the two studies revealed no evidence that autistic traits related to diminished implicit learning accuracy or efficiency. Instead, multilevel analyses again indicated that AQ-S scores related positively to LD. This finding is potentially consistent with Bayesian accounts of autistic perception. However, because evidence for an autism-related learning rate imbalance is inconclusive, and a contradictory interpretation of the studies' outcome could also be applied, it would seem unwise to accept this conclusion.

As noted previously, the positive relationship between autistic traits and LD comes with the important caveat that participants were required to attend to the characters' eyes throughout the learning phase. Attentional factors, such as the autism-related propensity to avoid, or be indifferent to, others' gaze (Chevallier et al., 2012; Hadjikhani et al., 2017; Tottenham et al., 2014) were therefore prevented from influencing learning in studies 2 and 3. However, it remains possible that attentional differences, related to autistic traits, might moderate learning from facial cues if this control were to be removed. The following study was designed to investigate this possibility.

Note to the reader: Studies 2 and 3, and the upcoming Study 4, share many methodological and procedural similarities. A more comprehensive discussion of the findings and limitations from all three studies can be found in the following chapter.

Chapter 6. Study 4: Implicit social learning without constrained attention to the eyes

6.1. Introduction

Studies 2 and 3 found *no* evidence that autistic traits related to a reduced capacity for implicit social learning. Instead, higher-AQ-S participants' social judgments were influenced by the undetected social cues to a greater extent than those lower in autistic traits. This finding contradicts both our general understanding of ASD, and of the social characteristics associated with sub-clinical autistic traits (Sasson et al., 2013; Wainer et al., 2011). The only two studies that had previously tested the relationship between autistic traits and implicit social learning found that higher autistic traits were associated with reduced learning (Hudson et al., 2012), or with reduced or unaffected learning, depending on the method of assessment (Macinska, 2019).

Participants in studies 2 and 3 undertook a task that required them to attend closely to the characters' eyes throughout the learning phase. As discussed in section 3.2.3., the eyes provide important information about others' emotions (Baron-Cohen et al., 2001a; Peñuelas-Calvo et al., 2019). However, people high in autistic traits may share a propensity to divert attention from the eyes, whether through gaze indifference (Chevallier et al., 2012; Moriuchi et al., 2017), or through gaze aversion (Corden et al., 2008; Joseph et al., 2008; Tottenham et al., 2014).

Gaze aversion, in particular, is a well-documented phenomenon in autistic individuals. Trevisan and colleagues (2017) scoured publicly accessible websites to collate qualitative descriptions of how people with autism experienced eye contact. Autistic people frequently reported that looking into others' eyes caused adverse reactions, such as feelings of fear, anxiety, dizziness, nausea and even physical pain. Others reported that they sometimes felt 'invaded' or 'violated' when other people looked into their eyes. Feelings of 'sensory overload' were also common, with many autistic individuals stating how mentally effortful it was to look into others' eyes. While Trevisan et al. (2017) also documented testimony that supported 'gaze indifference' (for example, opinions that eye contact felt 'pointless' and 'meaningless'), the majority of the qualitative descriptions indicated that eye contact can elicit unpleasant overstimulation in autistic individuals.[20]

Such adverse reactions may result, at least in part, from hyperarousal within the subcortical brain structures responsible for face processing and emotion regulation. Dalton and colleagues (2005) conducted an eye-tracking/MRI study in which they monitored brain activity as autistic and TD participants processed faces. The researchers found that autistic participants spent less time looking at the eyes than TD controls. More importantly, though, eye contact resulted in over-activation of the amygdala in the autistic, but not TD, participants which would be consistent with a heightened emotional response. Using similar techniques, Hadjikhani and colleagues (2017) investigated how autistic participants processed facial stimuli when they were (and were not) constrained to attend to the eyes. Especially when required to fixate on the eyes, autistic participants showed atypically high activation within the subcortical system, particularly the amygdala. Hadjikhani et al. (2017, pp. 3-4) went on to suggest that:

> *In everyday life, such oversensitivity may lead to attempts to decrease one's arousal levels, and first-hand reports suggest that simply avoiding to attend to the eyes of others is one common strategy among individuals with ASD. Such a strategy is unlikely, however, to come without costs, since the eyes carry important interpersonal and deictic information during social interaction and communication*.

6.1.1. Study 4 rationale and predictions

Attention to the eyes was particularly important to facilitate learning in studies 2 and 3. In the learning phases of both studies, not only did the characters' eyes provide important affective information, but gaze direction was manipulated to qualify the

[20] Trevisan et al. (2017) noted themselves that their data likely suffered from a selection bias. All experiential accounts were taken from public websites. It is reasonable to assume that people who suffer significant distress from eye contact would be the most likely to participate in forum discussions about autism-related eye contact difficulties. Conversely, autistic individuals who remained indifferent to eye contact (and therefore experienced less eye contact-related distress) would be considered less likely to participate in such discussions.

emotions as being directed toward (or away from) the viewer. Because the characters provided no verbal social cues, participants' social learning relied entirely on an implicit integration of emotional facial expressions and gaze directions. It is conceivable that, if the studies' gaze monitoring constraint were to be removed, participants higher in autistic traits may spend less time looking at the characters' eyes than those lower in autistic traits. Consequently, the higher autistic trait participants would be predicted to miss important social cues that would otherwise have assisted implicit learning. The current study was designed to test this prediction.

Study 4 used a near-identical learning phase to Study 2. Two characters again portrayed positive or negative social attitudes towards the participant by combining disgusted or happy facial expressions with changes in gaze direction. In Study 4's learning phase, however, the secondary task required participants to respond to the cessation of *any* movement, rather than changes in gaze direction. The specific requirement to monitor each characters' eyes was thus removed.

Study 2 demonstrated that 36 presentations of each characters' social cues produced a significant LD, the magnitude of which correlated *positively* with AQ-S. The current study tested whether, following identical cues, this correlational relationship would be reversed once participants were no longer obligated to attend to the characters' eyes. Such a finding would be consistent with suggestions that attentional differences, related to autistic traits, moderate implicit social learning from facial cues (Chevallier et al., 2012; Hadjikhani et al., 2017; Tottenham et al., 2014).

6.2. Method

6.2.1. Participants

Approval for Study 4 was granted by NTU's College Research Ethics Committee. All participants provided consent via an online form before taking part in the study. 69 participants (13 male, 54 female and 1 non-binary), aged 18 to 31 years old (mean age = 20.3, SD = 2.04) took part in testing, all of whom were recruited via NTU's Psychology Research Participation Scheme. Undergraduate students were incentivised to complete the study with the offer of research participation scheme credits. None of the participants had previously taken part in studies 2 or 3.

6.2.2. Task stimuli

Study 4 used near-identical video stimuli to Study 2. Please see section 4.2.2 for a full description. As before, actors were portrayed as having a positive or negative attitude toward the participant by manipulating combinations of gaze direction and facial expressions. Just as in Study 2, each participant saw three actors of the same sex. One actor consistently displayed pro-social cues, a second actor always displayed anti-social cues and a third actor appeared as a neutral distractor (and facilitator of catch trials). In the current study, only the videos of the neutral distractor differed from those used in Study 2, as will be described in the following section.

6.2.3. Task procedure

As in Study 2, testing took place online, with participants using a computer of their own choice. See section 4.2 for a full procedural description.

Learning phase: Just as in Study 2, participants viewed 96 video clips in total; 36 clips of the positive character, 36 of the negative character and 24 of the neutral distractor character. As described in section 4.1.2, Study 2 used a task to encourage sustained attention and to later identify participants who had not attended closely to the stimuli. In Study 2, participants watched the videos closely for eye movement. In videos that featured a change of gaze direction, participants pressed the spacebar as soon as the eye movement ended. If there was no eye movement in the video clip (as was the case with catch trials) participants were told not to press the spacebar. In the current study, the task simply required participants to press the spacebar when *any* movement of the character ended. Participants were also instructed *not* to press the spacebar if the video clip featured no movement. Aside from the corresponding changes made to the neutral distractor video clips (and to the task instructions), the learning phase in the current study was identical to the learning phase in Study 2.

Test phase: The test phase for Study 4 was identical to Study 2 and is summarised here only briefly. To establish that participants could differentiate between the faces of the learning-phase actors, they were first asked how many different individual actors had appeared (correct answer: 3). Participants then rated the positive and negative characters for likeability, using items from the Reysen Likability Scale (Reysen, 2005), before being assessed for explicit awareness of the characters' social cues. Participants were then tested for their ability to correctly identify the emotional facial expressions used throughout the learning phase. Finally, participants completed the AQ-S (Hoekstra et al., 2011), which quantifies self-reported autistic traits in adults with normal intelligence.

6.3. Results

6.3.1. Data reduction

For consistency, the data reduction criteria from Study 2 were retained. Please see section 4.3.1 for full descriptions of data reduction rationale and procedures.

Inattention to stimuli: Throughout the learning phase, participants faced catch trials during which the neutral character did not move. Participants responded correctly to catch trials by *not* pressing the space bar. Response accuracy to catch trials was high (mean correct = 98.7%), as was response accuracy on non-catch trials (mean correct = 99.3%). Therefore, no participants' data were excluded for reasons of inattention to the learning-phase stimuli.

Face differentiation: All participants stated that they had seen *at least* three individual people in the video clips. 87% of participants correctly stated that there were 3 individuals featured, while 13% responded that they had seen 4 or more actors. No participants were excluded for failing to differentiate between the faces of the characters.

Explicit awareness: To assess explicit awareness of the characters' social cues, participants were asked to describe patterns in gaze direction and facial expression. One participant showed evidence of explicit awareness for *both* positive and negative characters. A further 7 participants demonstrated explicit awareness of *either* the positive or negative character's cues. An unpaired two-sample t-test revealed no evidence that participants' self-reported autistic traits related to their development of explicit awareness. There was no significant difference in AQ-S total ($t_{(67)}$ = 1.31, p = .2) between explicitly aware participants (M = 59.25, SD = 9.91) and those who could not describe the social cues (M = 63.95, SD = 9.52). Data from all 8 explicitly aware participants were excluded from subsequent analyses.

Facial expression identification: Participants would have been excluded if they were unable to identify at least one example of a 'disgusted', 'happy' and 'neutral' facial expression. All participants surpassed this threshold, with 57 of the remaining 61 participants (93%) identifying all 6 facial expressions correctly.

Likeability ratings: As in the previous studies, data from Reysen Likability Scale (Reysen, 2005) 'item 5' were removed before analyses, leaving likeability ratings calculated from the 4 remaining items.

6.3.2. Implicit learning from social cues

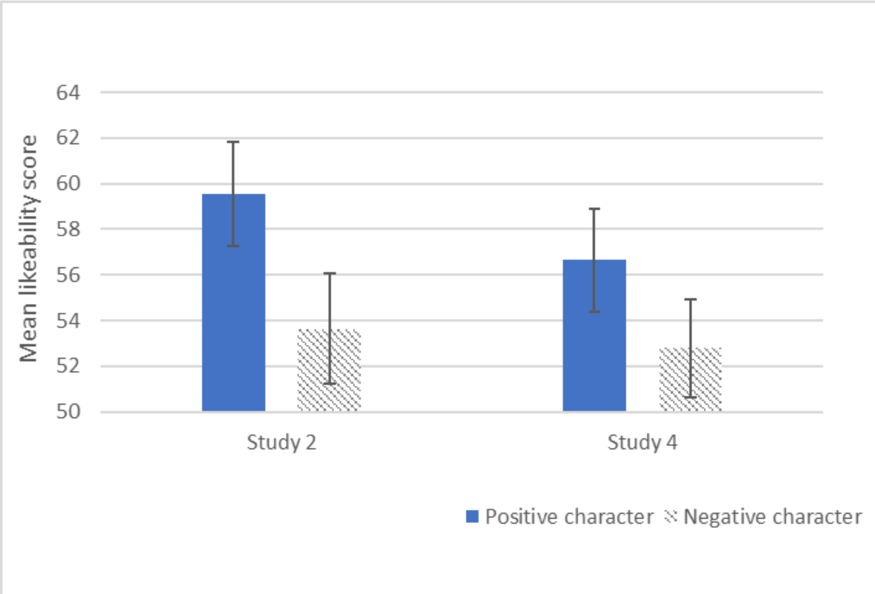
Study 2 found that implicit learning from the social cues influenced participants' likeability ratings, with the positive character (M = 59.5, SD = 15.6) rated as significantly more likeable than the negative character (M = 53.6, SD = 16.5, $t_{(46)}$ = 2.18, p = .034). However, this finding was not replicated in Study 4. With participants no longer required to closely monitor gaze direction, the positive character (M = 56.64, SD = 18.6) still elicited higher likeability ratings than the negative character (M = 52.78, SD = 16.84). However, a paired-samples t-test revealed that this difference no longer reached the level of statistical significance ($t_{(60)}$ = 1.19, p = .24). See **Figure 19** for likeability ratings with and without constrained attention to the characters' eyes.

6.3.3. Likeability difference and autistic traits

As in the previous studies, likeability difference (LD) was derived by subtracting a participant's mean likeability rating of the negative character from their rating of the positive character. Positive numbers indicated that the participants liked the positive character more than the negative character, with negative numbers indicating a preference for the negative character.

Figure 19

Likeability scores with and without constrained attention to the eye region

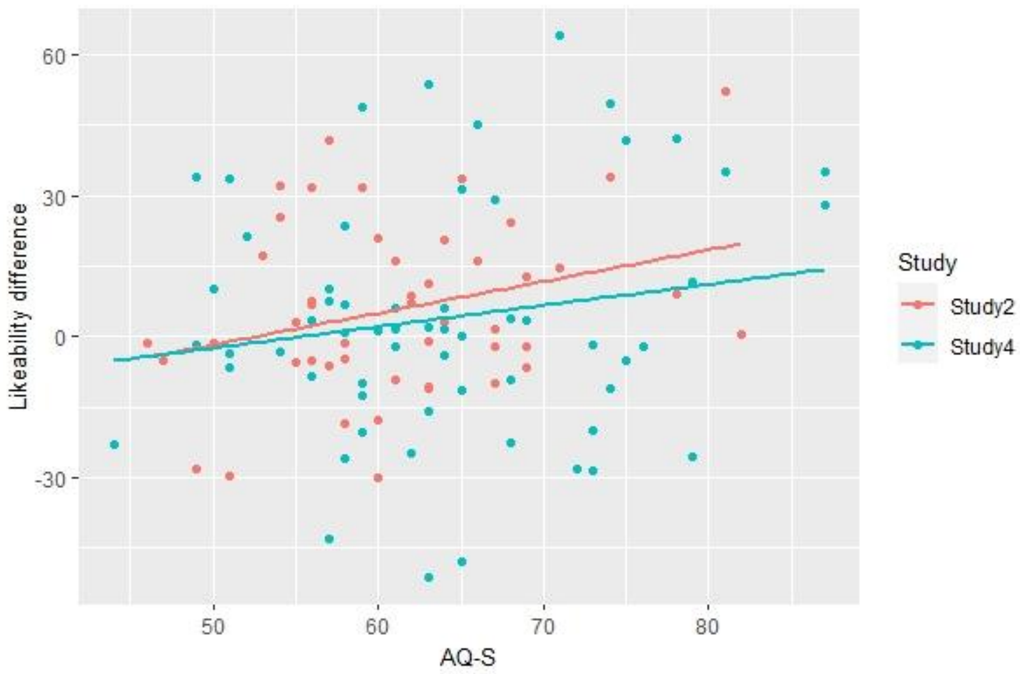


Note. Likeability ratings were provided via an unmarked 100-point sliding scale, where a score of 50 (the slider's midpoint and starting position) indicated a neutral opinion towards a character. The difference in likeability ratings between the positive and negative character was significant in Study 2 (where participants were required to monitor gaze direction), but not in Study 4 (where participants monitored video clips for any movement).

There was no significant difference between LD scores in Study 2 (M = 5.9, SD = 18.52), where participants monitored gaze direction, and those in Study 4 (M = 3.86, SD = 25.41, $t_{(106)}$ = 0.49, p = .63), where participants responded to general movement. In Study 2, LD and AQ-S were significantly positively correlated (Pearson's r = 0.29). In the current study, however, the correlation between AQ-S and LD was not significant (r = 0.17, $t_{(59)}$ = 1.32 p = .19). A linear regression on combined data from both studies, however, indicated that AQ-S still significantly predicted LD ($F_{(1,106)}$ = 4.42, p = .037) with a positive β slope coefficient of 0.5. See **Figure 20** for a plot of LD data from Study 2 and Study 4.

Figure 20

Correlations between LD and AQ-S in Study 2 and Study 4



Note. A small but significant positive correlation was found between AQ-S scores and LD in Study 2. Higher AQ-S scores (self-reported autistic traits) were associated with a greater difference between positive and negative character likeability ratings. No significant correlational relationship was evident in Study 4, where the supplementary task no longer required participants to closely monitor characters' gaze direction.

An ANOVA was conducted to check whether an imbalance of self-reported autistic traits (between the two studies) may have affected findings. The results revealed no significant differences in AQ-S total scores ($F_{(1,106)}$ = 2.23, p = .14) between participants in Study 2 (M = 61.36, SD = 8.08) and those tested for the current study (M = 63.95, SD = 9.52). Because Study 4 recruited only adult participants, age was not predicted to influence implicit learning. As in Study 2, a Pearson correlation test found no significant relationship between age and LD (r = -0.01, $t_{(59)}$ = -0.1, p = .92).

6.3.4. Multi-level analyses

As identified in the previous studies, data had the potential to be hierarchically organised in several different ways. Likeability scores may have been nested within actor conditions, participant sex, character sex or may have been influenced by whether or not the participant was the same sex as the characters they were rating ('same_sex'). See section 4.3.3 for a full explanation. The previous analyses indicated that, unlike in Study 2, there was no significant likeability score difference between positive and negative characters in Study 4, and no significant correlation between AQ-S and LD. However, if data *were* organised hierarchically, this would violate the requirement of most parametric analyses that residual terms are independent. Therefore, following the procedure outlined in section 4.3.3, data were again fitted to multilevel models that were capable of identifying and processing nested data.

To determine whether Study 4's data were organised hierarchically, they were first fitted to a baseline model (*intercept_only*) that predicted LD from just the intercept. Because individual actors had been shown to influence likeability ratings in the previous study, data were next fitted to a second model (*random_intercept_actor*) that allowed the regression line intercepts to vary by the actor who portrayed the positive character. A likelihood ratio test (likelihood ratio = 2.52, p = .11) indicated that *random_intercept_actor* fitted Study 4's data no better than the baseline model, suggesting that LD did not vary significantly between actor conditions. The procedure was repeated, creating separate models that allowed the intercept to vary by participant sex (*random_intercept_sex*), character sex (*random_intercept_char_sex*) and 'same_sex' (*random_intercept_samesex*). However, none of these models improved data fit over the baseline model, indicating no significant nesting of data within these variables.[21] Because none of the random intercept models superseded the baseline model, it is not surprising that the subsequent addition of AQ-S as a predictor (*add_AQS* model) also did not improve data fit (likelihood ratio = 1.78, p = .18). This null outcome supported the result of the earlier Pearson test, which indicated that the small positive correlation between AQ-S and LD was non-significant.

[21] Likelihood ratios and associated p values for alternative random intercept models: *random_intercept_sex* (likelihood ratio = 7.4e-8 p = 0.9998), *random_intercept_char_sex* (likelihood ratio = 7.9e-8, p = .9998) and *random_intercept_samesex* (likelihood ratio = 7.9e-8, p = .9998).

6.3.5. Comparing AQ-S/LD correlations from studies 2 and 4

Data from Study 2 (see section 4.3.3) and Study 4 (see previous section) were not organised hierarchically. A multiple regression was therefore conducted on the studies' combined data to test whether removal of the gaze monitoring requirement (Study 4) had significantly altered the positive AQ-S/LD correlation found previously. The model predicted LD from Study (Study 2 vs. Study 4) and AQ-S, and also tested for an interaction between Study and AQ-S. Because only the attention task differed between the studies' methodologies, a significant Study/AQ-S interaction would support the hypothesis that attentional factors moderated the relationship between autistic traits and social learning.

The regression model was a poor fit to the data ($F_{(3,104)} = 1.72$, $p = .17$, $R^2 = 0.05$). AQ-S no longer significantly predicted LD for Study 2 ($\beta = 0.67$, $p = .1$). For Study 4, neither the regression line intercept nor slope differed significantly from those estimated for Study 2.[22] Therefore, no significant interaction between Study and AQ-S was detected. This outcome was supported by a direct comparison of the AQ-S/LD correlation coefficients from the two studies. In Study 2, Pearson's r was 0.29 and significant. In Study 4, Pearson's r was 0.17 and non-significant. A Fisher z transformation (performed using R package *cocor*) allowed a comparison of these coefficients, finding no significant difference between the two ($z = 0.64$, $p = 0.26$).

6.4. Discussion: Studies 2, 3 and 4

Studies 2, 3 and 4 used the same online paradigm to investigate the relationship between dimensional autistic traits and implicit social learning. In each study's learning phase, a positive and a negative character conveyed their social dispositions toward participants via idiosyncratic combinations of gaze directions and facial expressions. Because no other social cues were given, participants' social learning depended on the

[22] The difference in the AQ-S/LD regression line intercepts between studies 2 and 4 was not significant (intercept was 10.32 points higher in Study 4, p = .75). Regression line slopes also did not differ significantly between studies (slope coefficient was 0.22 lower in Study 4, p = .67). No evidence of an interaction between Study and AQ-S was found.

successful implicit integration of these two cue types. In studies 2 and 3, participants attended closely to the characters' eyes throughout the learning phase. In these studies, participants with higher levels of autistic traits seemed the *most* capable of learning the characters' social dispositions. In Study 4, participants could allocate their attention more freely. Under this condition, no significant correlation between AQ-S and LD was found. The AQ-S/LD correlations from studies 2 and 4 did not differ significantly though, perhaps indicating a small effect size, a lack of power in the analyses or simply that altering the attention task had no significant effect on social learning. Regardless of these contradictory analytical outcomes, unlike the studies by Hudson et al. (2012) and Macinska (2019) no inherent link was found between autistic traits and reduced implicit social learning.

When seeking to interpret this pattern of results, it is worth remembering that all three studies applied the same data reduction/exclusion criteria. Essentially, participants' data were retained for analysis only if the participant; a) had attended to the learning-phase stimuli, b) could differentiate between the positive and negative characters, c) could recognise disgusted, happy and neutral facial expressions (displayed by those characters) and d) had no demonstrable explicit awareness of the learning phase social cues.

Chapter 3 discussed three factors that might theoretically contribute to autism-related implicit learning deficiencies within the social domain. The factors described were disrupted processing of affect/alexithymia (see section 3.2.2), reduced automatic theory of mind processing (section 3.2.3) and reduced attention to social stimuli (section 3.2.1). Alexithymia, at least at a superficial level, appeared not to affect the three studies' results. All non-excluded participants could, as described above, differentiate between the positive and negative characters *and* identify the task-relevant emotional facial expressions displayed by them. Similarly, reduced automatic ToM processing would do little to explain the pattern of results observed. If autistic traits related to a reduction in automatic ToM processing, one would predict a negative correlation between AQ-S and LD. Instead, when participants attended to the characters eyes (studies 2 and 3), a positive correlation was found. There was, however, evidence that attentional differences, associated with autistic traits, may have moderated implicit social learning.

Attending to the eye region can help individuals acquire knowledge of others' emotions and mental states (Baron-Cohen et al., 2001a; George & Conty, 2008; Peñuelas-Calvo et al., 2019). However, an autism-related propensity exists to divert attention from the eyes (Corden et al., 2008; Hadjikhani et al., 2017; Joseph et al., 2008; Moriuchi et al., 2017; Tanaka & Sung, 2016; Tottenham et al., 2014; Trevisan et al., 2017). When participants' attention was constrained to the characters' eyes (studies 2 and 3), gaze indifference and gaze avoidance behaviours were prevented from reducing opportunities for implicit social learning. Under this condition, higher self-reported autistic traits related to more accurate social judgements. However, when the 'attention to eyes' constraint was removed, participants were free to divert their attention to less socially informative areas of the screen. Because higher AQ-S participants would be considered the more likely to do so, it was originally hypothesised that these participants would miss more eye-based social cues and that, as a consequence, implicit social learning would decrease. As summarised below, this hypothesis received partial support from Study 4's findings.

The removal of the eye monitoring task (in Study 4) did not result in the predicted reversal of Study 2's positive AQ-S/LD correlation. However, when participants were no longer *required* to attend to the characters' eyes, no significant AQ-S/LD relationship was detected. Though the AQ-S/LD correlations did not differ significantly between the studies, the slope coefficient was lower in Study 4 than in Study 2. This combination of findings, though far from conclusive, could suggest a 'less positive' relationship between autistic traits and implicit social learning once participants could allocate their attention freely. Study 4 therefore supported the possibility that attentional factors, related to autistic traits, may influence individuals' ability to learn social information implicitly. While 'decreased spontaneous attention to the eyes' might explain why higher AQ-S participants' social learning was potentially reduced in Study 4, it does little to explain why their learning was superior in the earlier studies. Several potential explanations for this finding are discussed below.

6.4.1. Positive relationship between autistic traits and implicit social learning

No previous research has demonstrated a positive link between autistic traits and social learning. Instead, increased autistic traits usually relate to reduced social functioning and awareness (Sasson et al., 2013; Wainer et al., 2011). Because social difficulties are a hallmark of autism, it is problematic to account for the positive relationship found between AQ-S and LD in studies 2 and 3. Nevertheless, several candidate explanations for this finding are considered below.

Bayesian learning rate imbalance: As discussed in Chapter 5, the 'imbalance hypothesis' (Chrysaitis & Seriès, 2022) suggests that autistic cognition atypically prioritises the bottom-up processing of new information at the expense of the top-down influence of prior knowledge. This imbalance would conceivably lead to elevated 'learning rates' in people with higher autistic traits (Lawson et al., 2014; Van de Cruys et al., 2014). The positive relationship found between AQ-S and implicit social learning therefore appears consistent with the imbalance hypothesis. However, a recent systematic review found that Bayesian accounts of autism are only partially supported by evidence (Chrysaitis & Seriès, 2022). Furthermore, as discussed at length in section 5.4.1, it is equally possible to adopt a contradictory interpretation of Study 2 and 3's results. It would therefore seem unwise to accept the conclusion that the positive AQ-S/LD correlation necessarily relates to an autistic trait-related imbalance in learning rates. Other potential mechanisms for this finding are therefore presented below.

Local processing advantage: Autistic individuals have long been known to possess a bias towards local, rather than global, processing (Happé & Frith, 2006). Take, for example, performance on the Embedded Figures Test (Witkin, 1971). In this task, participants are presented with complex images that have simpler geometrical shapes embedded within them. When presented with a target shape, participants are required to locate that shape (within the larger complex image) as quickly as possible. Autistic individuals (Muth et al., 2014) and people higher in autistic traits (Cribb et al., 2016) tend to outperform controls on tasks of this type. This superiority is thought to reflect a tendency (and increased ability) to attend to and process small details, which enables faster and more accurate disembedding of the searched-for figures. While this processing style may relate negatively to real-life social functioning (Russell-Smith et al., 2012), it could potentially enable superior social learning in the artificial, screen-based paradigm used in studies 2 and 3.

In studies 2 and 3, the characters' eye regions were of particular importance. Firstly, eye monitoring was vital to successful completion of the 'reaction time' task. Secondly, and most importantly, the eye regions were not only key indicators of the characters' emotions/mental states (see section 3.2.1) but signalled where those emotions were directed (towards, or away from, the participant). Monitoring of the eyes was therefore essential in facilitating implicit learning of the characters' social dispositions. A further possibility is that a heightened, sustained focus on just the characters' eyes (i.e., local processing) would have maximised learning opportunities to the greatest extent.

Individuals high in autistic traits may be the least likely to scrutinise others' eyes in real social situations (see sections 1.5.4 and 3.2.1). However, when the eyes are useful for completing a task, even clinically diagnosed autistic participants have been shown to attend to them closely (see, for example, Ristic et al., 2005, described on page 23). In studies 2 and 3, low-AQ-S participants (with their preference for global processing) may have continued to perceive the characters' faces as gestalt stimuli. However, those higher in autistic traits (with their preference for local processing) may have been more singularly focussed on the specific region vital for completing the secondary RT task – the characters' eyes. It is possible that attending to the eyes in this way could have facilitated superior implicit learning from the (heavily eye-based) social cues. Though not supported by evidence from the current studies, the autism-related preference for local detail could therefore potentially explain the positive correlation found between AQ-S and LD.

Increased attention to learning-phase stimuli: Because COVID restrictions threatened to interrupt in-person data collection, all three studies were conducted online. While the controlled environment offered by a laboratory would have been preferable, participants used a computer of their choice at a time and location of their choosing. A possible limitation of studies 2, 3 and 4 was that no information was collected about the environments in which testing took place.

Though not supported by data, it is conceivable that participants' 'testing location' choices varied systematically with their autistic traits. For example, it is possible that high AQ-S participants chose quieter, more isolated environments, or generally experienced fewer disturbances during testing, than those lower in autistic traits. Such factors could, in turn, have created conditions that allowed more focussed attention on the online task, maximising opportunities for social learning. Even if one's capacity for implicit learning is otherwise unrelated to autistic traits, such a mechanism could hypothetically promote the correlation observed between AQ-S and LD.

This suggestion is, at least, partially supported by evidence. Autistic traits are known to correlate with sensory abnormalities in individuals with and without ASD (Horder et al., 2014; Robertson, A. E. & Simmons, 2013; Robertson, C. E. & Baron-Cohen, 2017a). Furthermore, recent research indicates that the autism-related reduction in social attention is amplified when perceptual load increases. Using a virtual reality eye-tracking paradigm, Haskins et al. (2022) demonstrated that autistic individuals spent less time (than TD controls) attending to social elements of their environment in noisier, more distracting conditions. It might therefore be predicted that individuals higher in autistic traits would select the least distracting environments to participate in an online 'facial expression processing' study. While there was no evidence that self-selected testing environments varied with autistic traits in studies 2-4, it is worth monitoring this variable in future online studies. Because the threat of COVID restrictions eventually lifted, the final study in this thesis was conducted back in the laboratory to eliminate any effect of variable testing conditions.

There is another potential attention-related explanation for the positive AQ-S/LD correlation found in studies 2 and 3. As demonstrated in numerous studies, individuals with higher autistic traits also tend to have an increased interest in seeking and identifying patterns (see Crespi, 2021 for a summary). As mentioned previously, the AQ-S (Hoekstra et al., 2011) includes a 'fascination for numbers/patterns' sub-scale. When the relationships between AQ-S subscale scores and LD were analysed (see section 5.3.4), only the correlation between 'numbers/patterns' and LD approached the level of statistical significance ($p = .058$). Because of their elevated interest in identifying patterns, higher AQ-S participants may theoretically have been the most intrigued by a novel 'face processing' psychology study. As such, they may have attended to all aspects of the study (including the learning phase videos) more diligently than lower-AQ-S participants. This heightened, undivided attention could, in turn, have optimised high-AQ-S participants' potential for implicit social learning.

The studies presented in this thesis were not designed to assess, in detail, how closely participants attended to the learning-phase videos. However, catch trials were embedded within the learning phase secondary tasks to identify *inattention* to the stimuli. Further analysis of the data from studies 2 and 3 found that catch trial performance (percentage of catch trials responded to correctly) was *not* predicted by AQ-S ($F_{(1,138)} = 0.39$, $p = .54$). Therefore, no evidence was found to suggest a link between autistic traits and generally enhanced attention to the learning-phase videos. As there was also no evidence available to support a link between autistic traits and the selection of quieter testing environments, it is not currently possible to conclude whether or not attentional differences promoted the positive correlation between AQ-S and LD. However, it is suggested that attentional mechanisms, such as those discussed above, should be investigated more systematically in future online studies.

On-screen versus 'live' social stimuli: While not an issue specific to online testing, there is a potential disconnect between participants' behaviour during screen-based tasks and behaviour during live social interactions. Prepared stimuli, presented on screen, have of course been used in countless studies in multiple fields of psychology. Such methods have undoubtedly advanced our understanding of social attention and learning in those with autism. However, research has also called into question the ecological validity of such studies.

Freeth and colleagues (2013) tracked TD participants' gaze during social interactions with an experimenter, who either appeared on screen or was physically present in the room. Many measures of social attention (for example, time spent looking at the experimenter) were consistent between conditions. However, the researchers also found significant differences between the conditions. Experimenter eye contact was shown to influence viewing patterns during the 'in person' but not during the 'on screen' condition. Participants with increased (but subclinical) autistic traits spent less time looking at the experimenter's face during on-screen interactions only.

Utilising similar methods, Grossman et al. (2019) used a within-participant design to test whether looking behaviours during the presentation of on-screen social stimuli predicted gaze patterns during in-person interactions. Autistic and TD adolescents' gaze patterns were monitored as they viewed pre-recorded videos of people talking. A comparable spatial layout was maintained when the video screen was subsequently replaced by a live conversation partner. Against predictions, the researchers found no group differences in face-directed gaze during live interactions. However, compared to the TD participants, the autistic group spent significantly less time looking at the faces during the screen-based task. Grossman et al. (2019) concluded that while 'on-screen' gaze patterns predicted 'live social interaction' gaze patterns for the TD participants, this was not the case for those with autism.

Perhaps because of the technical challenges of monitoring gaze precisely during live social interactions, neither study reported on participants' looking behaviour to the eye regions specifically. As mentioned previously, the characters' eyes were a particularly rich source of social information in the learning phases of studies 2-4. No eye-tracking evidence yet exists that would support an attentional basis for the positive correlation found between autistic traits and LD. However, taken together, the studies cited above indicate that high-autistic-trait individuals may allocate their attention quite differently when exposed to social cues on screen and in person. Study 4 showed that implicit social learning may be moderated by attentional factors linked to autistic traits. It is possible that the moderating mechanism, or mechanisms, relate specifically to the online/on-screen presentation of social cues. Further research would, of course, be required to establish evidence for such a mechanism.

Influence of other moderating variables: Because studies 2-4 were conducted online, the task duration was kept deliberately short (10-15 minutes). This precaution was taken to help guard against fatigue effects, to minimise interruptions during testing and, ultimately, to reduce participant drop-outs. The short task duration did, however, limit the breadth of data that could be collected. In particular, the online studies were too brief to assess certain participant attributes that had the potential to influence implicit learning task performance.

As described in section 3.2.2, autistic participants' performances on 'traditional' theory of mind (ToM) tasks are heavily moderated by language ability and intelligence (Gao et al., 2023; Gernsbacher & Yergeau, 2019). Implicit social learning in studies 2-4 should, theoretically, have been relatively unaffected by these attributes. Intelligence is not generally predictive of implicit learning ability (Gebauer & Mackintosh, 2007; McGeorge et al., 1997) and the three studies' language demands were not considered high for their (mostly TD) adult participants. However, because neither Hudson et al. (2012) nor Macinska (2019) collected data on intelligence or language ability, their influence on the implicit social learning paradigm employed is unknown. It remains possible that individual differences in these attributes covaried with participants' subclinical autistic traits, and that IQ and/or linguistic ability influenced implicit learning in a direct, but unexpected, way. In the final implicit social learning study in this thesis, participants also completed measures of non-verbal intelligence and vocabulary. These attributes could then be controlled for when analysing the relationship between autistic traits and social learning (see Chapter 7).

Summary: The positive relationship between autistic traits and LD, when attention was constrained to the characters' eyes, remains largely unexplained. Several candidate explanations were considered. Additional weight assigned to new information in high-autistic trait participants' perceptions (the imbalance hypothesis), would be consistent with the correlation observed. However, wider evidence for this cognitive preference remains inconclusive (Chrysaitis & Seriès, 2022). The autism-related preference for local processing is better supported by evidence and could also be consistent with the positive AQ-S/LD correlation found in studies 2 and 3. Attention-based explanations were also considered. Higher autistic trait participants may have selected testing environments more conducive to effective implicit learning. Similarly, high AQ-S individuals may have attended to the videos more diligently due to a heightened interest in identifying patterns. However, no evidence exists to support the first suggestion, and analysis of catch trial data provided no support for the second. While higher autistic traits are associated with 'real world' social difficulties, the online/on-screen presentation of social stimuli in studies 2 and 3 may have facilitated social learning for higher AQ-S participants (when attention was constrained to the eyes). However, further research would be required to investigate this phenomenon. Finally, intelligence and language ability (which are known to affect performance on various traditional ToM tasks) may have moderated implicit social learning in an unpredicted way.

6.4.2. High variability in likeability assessments

Character likeability ratings varied greatly in all three studies. Even in Study 2, where the positive character was rated as significantly more likeable than the negative character, only 9% of the variation in LD was attributable to participants' self-reported autistic traits. With 91% of LD variation yet to be accounted for, it seems likely that several factors, additional to the social cues and participants' autistic traits, influenced participants' likeability ratings. Multilevel analysis identified 'actor condition' (the particular actors who portrayed the characters) as one such factor. Other potential factors are discussed below.

This high variability in likeability ratings (and the resulting high standard deviations that underlay statistical analyses) perhaps gave rise to some of the studies' seemingly contradictory findings. For example, the positive character was rated as significantly more likeable than the negative character in Study 2 (constrained attention to the eyes), but not in Study 4 (free allocation of attention). However, data analysis also indicated that LD was *not* significantly different between these two studies.

Measures were, of course, put in place to control for extraneous variables. These measures included random allocation of participants to actor conditions, a counter-balanced order in which participants rated the characters for likeability and the use of 'within participant' LD as the measure of social learning. While such precautions should have ensured that extraneous factors, such as individual preferences, did not skew data in a particular direction, the high variability in likeability assessments remained.

Additional variability may have arisen from the specific measure chosen to assess character likeability. Participants responded to items from the Reysen Likability Scale (Reysen, 2005), the only published example of such a scale and one that was chosen for reasons of reliability and validity. However, the Reysen scale was developed using undergraduate students. As such, several of its items, such as 'I would like this person as a roommate' were judged inappropriate for use with a mixed age sample in studies 2-4. For this reason, and to keep online participation time to a minimum, only five items from the Reysen scale were administered after the learning phase. One of these items ('This person is similar to me', see section 4.3.1), was later discarded because responses to it were not consistent with those to the other items. The Reysen scale was therefore not used in its entirety, nor was it administered to an exclusively undergraduate sample. While the four remaining Reysen items demonstrated excellent internal consistency in Study 2 (see, again, section 4.3.1), their validity could no longer be determined. Because of this uncertainty, and to assess participants' knowledge of the characters' social dispositions more directly, the method used to assess character likeability was amended in the final study (see Chapter 7).

With such high variability in likeability ratings, it is possible that real relationships between autistic traits and implicit social learning were masked. For example, Study 3 tested the hypothesis that autistic traits may relate to reduced implicit learning efficiency (rather than accuracy). Consistent with this hypotheses, AQ-S and LD were significantly positively correlated following 36 exposures to each character's learning-phase videos (Study 2). The gradient of the correlation was reduced after 24 exposures, and after 12 exposures the AQ-S/LD trendline was slightly negative. However, perhaps because of the high variability in likeability ratings, multilevel analyses did not detect a significant effect of exposure condition. Similarly, no significant difference was found between Study 2's (significant) positive AQ-S/LD correlation and the non-significant correlation found in Study 4, where participants were no longer required to attend to the characters' eyes. By testing higher numbers of participants in future studies, it may be possible to detect the relatively small effect of autistic traits on implicit social learning amid highly variable likeability ratings.

6.4.3. Range of participants' autistic traits

Like Hudson et al. (2012), the majority of participants recruited to studies 2-4 were social science undergraduates who had not received an autism diagnosis. Hudson and colleagues noted that the range of self-reported autistic traits amongst their participants was somewhat narrow. Because Hudson et al.'s participants were also generally low in autistic traits, this may have limited the generalisability of their findings. It seemed possible that the current studies' recruitment strategy may have led to similar concerns.

Studies 2-4 used the AQ-S to quantify participants' autistic traits. AQ-S scores could range from 28 (indicating no autistic traits) to a maximum score of 112. While developing the AQ-S, Hoekstra et al. (2011) found that a score of ≥70 distinguished individuals with HFA from TD controls with a sensitivity of .94 and a specificity of .91. After the exclusion criteria were applied, 201 participants' data were retained for analyses across the three studies. Individuals' AQ-S scores ranged from 41 to 87 (M = 62.52, SD = 9.11), with 40 participants (19.9%) obtaining AQ-S totals of 70 or more. It therefore appeared that the sample recruited to the online studies contained a relatively broad range of autistic traits. Indeed, a sizeable proportion of participants obtained scores representative of clinically significant autistic traits.

6.4.4. Summary and conclusions

Within this short series of studies, TD participants, with varying levels of autistic traits, demonstrated the ability to acquire implicit knowledge of characters' social dispositions from dynamic emotional facial stimuli. This knowledge later influenced social perceptions of those characters, seemingly without the participants being aware of it. The overarching finding from studies 2-4 was that participants with greater autistic traits gave character likeability ratings which were better aligned with the undetected social cues. However, this relationship was potentially contingent on constrained attention to the characters' eyes. When participants attended closely to the characters' eyes (studies 2 and 3), higher AQ-S scores were associated with more accurate likeability judgements. However, when participants allocated their attention more freely (Study 4), no evidence of this relationship was found. Though the AQ-S/LD correlations did not differ significantly between studies 2 and 4, it seems possible that attentional factors, including the autism-related propensity to divert attention from others' eyes (Chevallier et al., 2012; Hadjikhani et al., 2017; Tottenham et al., 2014), may moderate the ability to learn implicitly from facial cues. Importantly, unlike the studies by Hudson and colleagues (2012) and Macinska (2019), studies 2, 3 and 4 found *no* evidence that autistic traits related to inferior implicit learning of social information.

Several limitations to these studies were discussed. Data collection took place online, which meant that it was not possible to control participants' testing environments. Because self-selected testing conditions had the potential to affect learning, the final study in this thesis was conducted under laboratory conditions (see the following chapter). The short online format of studies 2-4 also made it difficult to assess attributes, such as linguistic ability and intelligence, which could potentially influence learning task performance. This omission was also rectified in the final study. Finally, while studies 2-4 did recruit participants with a broad range of autistic traits, few autistic individuals took part in testing. The final study in this thesis was designed to test whether individuals with a clinical ASD diagnosis differed from non-autistic individuals on measures of implicit social learning.

Chapter 7. Study 5: Implicit social learning and its subsequent influence on cognition

7.1. Introduction

Study 2 demonstrated that TD participants could acquire implicit knowledge of characters' social dispositions after exposure to a series of dynamic facial cues. This knowledge later influenced social perceptions of the characters without the participants becoming aware of it. This finding seems consistent with suggestions that at least some elements of social intuition may be subserved by implicit learning processes. However, in Study 2 (and studies 3 and 4) implicit learning was quantified by *explicit* ratings of character likeability, given under no time pressure. Conversely, successful participation in real-world social interactions is thought to depend on the *rapid* automatic integration of implicitly learned information into social cognitive processes (Lieberman, 2000).

None of the previous studies in this thesis found evidence that autistic traits related to poorer implicit social learning. Instead, when participants' gaze was constrained to the characters' eyes, higher AQ-S scores were associated with improved social learning. It is well-established, however, that increased autistic traits usually correlate with decreased social awareness and functioning (Sasson et al., 2013; Wainer et al., 2011). The current study was designed, in part, to investigate a mechanism that could potentially reconcile these opposing findings.

It is possible that people with autism (or higher autistic traits) retain a typical ability to learn even social information implicitly. However, it may be the subsequent influence of that learning on related cognitive processes that is diminished. Such a 'disconnect' might explain, for example, why autistic individuals often resort to using explicit compensatory strategies to navigate social encounters (Hull, L. et al., 2017; Tierney et al., 2016), though 'executive dysfunction' accounts of autism also appear consistent with this phenomenon (Burroughs et al., 2024; Fong & Iarocci, 2020; Leung, R. C. et al., 2016; Torske et al., 2018).

Nevertheless, if implicitly learned information is not as readily available to automatically guide social cognition, this could conceivably result in the real-world social difficulties (and the increased reliance on explicit 'social rules') seen in autism. The final study was designed to investigate how the learning phase from Study 2 (which fostered effective implicit learning in high-AQ-S participants) influenced autistic and TD participants' subsequent cognition, as quantified by performance on an affective priming task (described below). The rationale for this experiment, and its hypotheses, are set out in the following sections.

7.1.1. Emotional faces and the affective priming effect

Faces are an important source of information about others' mental states and intentions (Ferretti & Papaleo, 2019; Hadders-Algra, 2022). Perhaps because of their fundamental value to human communication, faces are detected and categorised more rapidly than most other stimuli (Palermo & Rhodes, 2007). In particular, faces displaying clear emotional expressions receive prioritised attentional and cognitive resources (Armaghani et al., 2014; Palermo & Rhodes, 2007; Vuilleumier & Schwartz, 2001). In TD adults, for example, emotional faces are detected more quickly (Calvo & Nummenmaa, 2008) and categorised more accurately (Calvo & Esteves, 2005) than neutral faces. Indeed, a large body of evidence suggests that, by the time we reach adulthood, our brains are adept at the fast automatic processing of faces and emotional facial expressions (Schindler & Bublatzky, 2020).

One fundamental feature of any emotional stimulus (especially pertinent to, but not limited to, faces) is its affective valence, or hedonic tone. Valence refers to a stimulus' perceived quality of being 'good' or 'bad', 'pleasant' or 'unpleasant' (Kuppens et al., 2013). Valence is not an intrinsic feature of any given stimulus but is influenced by prior experience. For example, while most people learn to attach a strong positive valence to 'kittens' (Warriner et al., 2013), individuals with a phobia of cats almost certainly do not. Similarly, an otherwise attractive smiling face (which might typically be perceived as positively valenced) could be perceived negatively if it belonged to someone with whom one argues frequently.

Once a particular valence has become associated with a stimulus, that valence is generated automatically by the brain's limbic systems whenever that stimulus is presented (Berridge, 2019). It is generally accepted that valence is intrinsically motivating and exerts an important influence on decision making (Barrett, 2006; Carruthers, 2018; Wilson & Gilbert, 2005). Certainly, once a face is detected, its affective valence is processed rapidly and automatically, providing a near-immediate influence on subsequent cognitive processes (Aguado et al., 2012; Neta et al., 2011; Stone & Valentine, 2004; Todorov et al., 2011).

The affective priming paradigm (Fazio et al., 1986) has frequently been employed to investigate the implicit processing of valence and its subsequent influence on cognition. In a classic affective priming study, a prime word (with a positive or negative valence) and a target word (with a positive or negative valence) are presented to participants sequentially. Participants are asked to indicate the valence of the target as quickly as possible. Known as the 'affective priming effect', participants' responses to the target are usually faster when prime and target are valence-congruent (for instance when prime and target are both positive) than when they are incongruent. As an example, most people perceive 'cockroach' as negatively valenced (Warriner et al., 2013). When 'cockroach' is presented as a prime, participants are faster to indicate the valence of a negative target word ('disgusting') than an incongruously positive word ('appealing', Fazio, 2001).

According to associative network models, spreading activation amongst related concepts automatically facilitates the faster responses to targets when their valence matches that of the prime (Fazio, 2001; Herring et al., 2013). The affective priming effect is, therefore, believed to index the rapid implicit processing of the prime's valence. This conclusion is supported by findings that the effect is best (or sometimes only) detected at stimulus onset asynchronies (SOAs) of 300ms and under, which are too short to allow slower, explicit processes to influence decision making (Herring et al., 2013). Once SOAs reach 1000ms, when conscious effortful processes *can* affect decisions, the affective priming effect is usually eliminated (Aguado et al., 2007; Fazio et al., 1986; Fazio, 2001; Hermans et al., 2003; Herring et al., 2013; Stenberg et al., 1998). At short SOAs though, affective priming has proven a robust phenomenon across decades of research (Herring et al., 2013), though few studies have attempted priming using facial stimuli.

Priming using emotional faces: The handful of studies that have examined affective priming effects using faces have produced an interesting mix of findings. Several early studies produced findings broadly in line with classic affective priming experiments. In the first study to use emotional faces as primes, Murphy and Zajonc (1993) found that extremely brief presentations (4ms) of smiling or angry faces influenced participants' subsequent ratings of unfamiliar ideographs. Seemingly meaningless symbols were rated as more likeable following happy faces than angry faces. Stenberg and colleagues (1998) later used compound stimuli (positive or negative target words superimposed onto happy or angry/sad faces) to show that, when the faces and target words were valence-incongruent, participants were slower to indicate the valence of the words. Banse (2001) found that the faces of liked persons (participants' close friends or romantic partners) and disliked persons (Sadam Hussein) elicited a significant congruence effect when priming target words. Aguado et al. (2007) also demonstrated that happy, angry and fearful facial expressions elicited a classic affective priming effect for positive and negative targets. The effect remained even when participants were given explicit instructions to process a non-affective property of the prime (gender of the person in photograph). However, a more recent study by Conte and colleagues (2018), which used emotional faces as both primes *and* targets, produced more nuanced findings.

Conte et al. presented TD participants with happy or angry face primes followed by happy or angry face targets (SOA 400ms, see Experiment 2B). Similar to a classic affecting priming task, participants had to indicate the target's facial expression (using two buttons labelled 'happiness' and 'anger') as quickly as possible. Unusually, Conte et al. did not report results for an overall congruence effect, instead choosing to analyse congruent and incongruent trials separately. During congruent trials, angry faces produced what they termed a 'negative priming effect'; angry primes (followed by angry target faces) produced slower responses than happy primes (followed by happy targets). For incongruent trials, there was no significant difference in response times between the two prime types. Conte et al. speculated that angry faces may have conveyed 'threat', and therefore demanded increased cognitive resources (compared to happy faces), reducing processing speed.[23] Because Conte et al. used a SOA of over 300ms, it is possible that slower, explicit cognitive processes may have influenced their findings.

[23] Anger-induced threat was one of several potential explanations advanced by Conte et al. (2018). As in the previous studies in this thesis, Study 5 used disgusted (rather than angry) facial expressions to avoid introducing 'threat' as a potential confound.

Their study did, however, demonstrate that priming using emotional faces could produce effects other than a classic valence congruence effect.

The studies cited thus far used either words or static emotional faces as affective primes. However, the current study was designed to investigate how *implicit learning* from emotional facial cues affects performance on a subsequent affective priming task. To the author's knowledge, no previous studies have attempted to answer this question directly. However, two previous studies investigated a related concept.

Implicit *processing* and the affective priming effect: Jellema and colleagues (2011) conducted a short series of experiments which showed that participants' judgements of emotionally neutral faces could be influenced by recent perceptual history. TD participants watched videos in which faces transitioned from maximally happy or angry expressions to neutral facial expressions. Participants consistently rated the 'final frame' neutral faces as 'slightly happy' in the angry-to-neutral condition, and as 'slightly angry' in the happy-to-neutral condition. The authors speculated that participants may have implicitly tracked the characters' emotional states and automatically anticipated a continuation of their emotional transition. For example, after observing a face transitioning from angry to neutral, participants' distorted (slightly happy) ratings of that neutral face may have reflected an implicit projection that the character's mood continued to improve. Jellema et al. then used the same 'overshoot illusion' videos in an affective priming task. Participants made speeded valence decisions about positive or negative target words which had been superimposed onto the 'final frame' neutral faces. Significant valence congruence effects were found in line with the perceptual distortions demonstrated in the initial experiment. In other words, after viewing videos that caused participants to perceive a neutral face as 'slightly happy' in Experiment 1, participants were faster to evaluate positive target words than negative target words. This result was consistent with the perceptual overshoot carrying with it a related valence which influenced response speeds in the affective priming task (Jellema et al., 2011).

Macinska (2019, Experiment 12) recreated Jellema et al.'s affective priming study, this time testing both TD and autistic participants. She also used morphed images from the Warsaw set of Emotional Facial Expressions Pictures (WSEFEP, Olszanowski et al., 2015) to increase the ecological validity of the overshoot illusion videos. As in Jellema et al.'s study, the TD group evaluated positive words fastest when they were preceded by angry-to-neutral videos. TD participants also evaluated negative target words fastest in the happy-to-neutral condition though, after Bonferroni correction, the effect was no longer significant. While TD participants showed at least some evidence of priming in line with the perceptual illusion, the autistic group did not. This result was particularly noteworthy because autistic participants had previously demonstrated their susceptibility to the overshoot illusion. When simply evaluating the emotion shown in the 'final frame' neutral faces of similar video stimuli, autistic participants experienced a similar perceptual distortion to the control group (Palumbo et al., 2015).[24]

While the absence of an affective priming effect in the autistic participants could be interpreted in terms of a potential 'disconnect', the overshoot perceptual illusion is, at best, distantly related to the type of implicit social learning central to this thesis. Also, the timings used throughout Jellema et al.'s (2011) and Macinska's (2019) affective priming tasks did not exclude the possibility that slower explicit processes influenced findings. As discussed previously, classic affective priming effects are most reliably detected at SOAs of 300ms or lower. The video stimuli in Jellema et al.'s study were 470ms long (450ms for Macinska), with the final neutral face and target word displayed for 3000ms (or until participants responded). With a SOA above 300ms, and with participants responding under little time pressure, Jellema and colleagues rightly acknowledged that both implicit and explicit cognitive processes may have contributed to their findings. This issue was rectified in the current study.

7.1.2. The current study

Study 5 built on previous research by investigating whether an autism-related disconnect exists between implicit social learning and its subsequent influence on cognition. Study 2 showed that, following a learning phase that implicitly established characters as either pro- or anti-social, higher AQ-S participants gave character likeability ratings that were better aligned with the undetected social cues. As the

[24] Further experimental manipulations by Palumbo and colleagues indicated that, while susceptibility to the overshoot illusion was similar in TD and autistic participants, different cognitive mechanisms may have subserved the effect. TD participants tended to engage in automatic emotional anticipation, whereas autistic participants may have been influenced primarily by visual features of the video stimuli (Palumbo et al., 2015).

current study used a near-identical learning phase, it was predicted that this relationship would be replicated. Because 'liking' and valence are so closely linked (Berridge, 2019), participants were expected to attach a positive valence to the pro-social character and a negative valence to the anti-social character. Static neutral-faced images of the two characters were then used as primes in an affective priming study. Because the prime photographs featured neither positive nor negative emotional facial expressions, their presentation was expected to influence target word evaluation speeds only if participants had earlier learned the characters' 'hidden' dispositions.

Previous research with TD participants showed that the presentation of static emotional faces could elicit a classic affective priming effect (Aguado et al., 2007), but that angry face primes may also inhibit the speed of responses to target words (Conte et al., 2018). While neither of these effects required implicit social learning to have taken place, it was hypothesised that the neutral face photographs in the current study would elicit priming effects in (at least) one of these two directions.

Primarily, TD participants were predicted to show evidence of a valence congruence effect. TD participants were predicted, for example, to evaluate positive words fastest after the (positively valenced) pro-social character's neutral face was presented. Based on the findings of Conte et al. (2018), the anti-social character's neutral face was predicted to potentially inhibit TD participants' response speeds, possibly to all target words, or to congruent (negative) target words specifically.[25] Importantly, though, the absence, or relative reduction, of *any* priming effect (whether predicted or not) in autistic participants specifically would be consistent with a disconnect between implicitly learned information and its subsequent influence on cognition. A negative relationship between participants' autistic traits and the magnitude of any priming effect could, likewise, be considered consistent with a disconnect.

Seemingly in line with the disconnect hypothesis, overshoot illusion videos were shown to produce an affective priming effect in TD, but not autistic, participants (Macinska, 2019). However, Macinska's participants were not restricted to stimulus presentation

[25] Conte et al. (2018) used 'anger', rather than 'disgust', as the negative prime facial expression. This second hypothesis was retained for the current study on the assumption that Conte et al.'s 'negative priming effect' was not necessarily contingent on anger-induced 'threat', which was just one of the potential mechanisms suggested by Conte and colleagues. If the effect could be elicited by more general negative-valenced stimuli, it could conceivably be induced by 'disgust' in the current study.

timings and response windows that ensured that processing remained implicit. This problem was remedied in Study 5 via the use of a 300ms SOA and a response window of just 1000ms. These measures were shown to facilitate rapid implicit processing in previous studies (Conte et al., 2018; Hermans et al., 2003; Hietanen et al., 2007).

7.2. Method

7.2.1. Participants

Approval for this study was granted by Nottingham Trent University's College Research Ethics Committee. All participants were recruited via word of mouth, social media channels or via NTU's Psychology Research Participation Scheme. Undergraduate NTU students received research participation scheme credits upon completion of testing. Other participants were incentivised to participate with the offer of a £10 Amazon voucher. None of the current study's participants had previously taken part in studies 2, 3 or 4.

Autistic participants: 26 participants (10 male, 14 female and 2 non-binary, aged 18 to 62 years old, mean age = 31, SD = 14.18) reported that they had previously received an ASD diagnosis. These diagnoses were not verified by the researcher. However, participants later completed the AQ-S, which quantifies traits associated with autism. 25 of the 26 autistic participants surpassed the AQ-S's 'stringent cut-off score' of 70 (M = 84.38, SD = 9.64), which reportedly distinguishes HFA from TD individuals with a sensitivity and specificity of 0.94 and 0.91, respectively (Hoekstra et al., 2011).

TD participants: 58 adult participants (28 male, 29 female and 1 non-binary, aged 18 to 64 years old, mean age = 24, SD = 7.25) also took part in testing. All 'control group' participants confirmed that they had never received an autism diagnosis. The mean AQ-S score of the non-autistic participants was 61.91 (SD = 11.48).

Later analyses revealed that, even after applying exclusion criteria, the two groups differed significantly on age as well as several other variables. Please see section 7.3.1 for further details.

7.2.2. Learning phase materials and procedure

After being welcomed to the laboratory, participants sat in front of a Lenovo desktop computer approximately 50cm from a 68.5cm (27 inch) screen. All computerised tasks were developed using Gorilla Experiment Builder. Participants were first presented with information pages that described the experiment as a study investigating individual differences in face and word processing. Aside from the omission that the study's main interest was in implicit social learning, all information provided was accurate. After completing a consent form, participants provided demographic information, including whether they had ever received an autism or Asperger's diagnosis. Before starting the task, participants confirmed that they were native English speakers and had normal vision, or were wearing glasses/contact lenses that corrected their vision to normal.

The learning phase of Study 5 was identical to that used in Study 2, with one exception. Data from studies 2 and 3 indicated that female actors KP and OG were similarly able to influence 'likeability' in line with their implicit social cues. Conversely, male actor MG tended to receive lower likeability ratings than male actor PA, regardless of the social cues displayed. Because the earlier studies also found no significant effect of 'character sex' (male and female characters generally received similar likeability ratings) or 'same sex' (characters received similar likeability ratings whether or not they were the same sex as the participant), only the female actors/characters were used in the current study. Therefore, in Study 5, participants viewed short videos in which female actors displayed a combination of cues that portrayed a positive or negative social disposition toward the viewer. One actor consistently displayed positive disposition cues, a second actor always displayed negative cues while a third actor appeared as a neutral distractor (see **Figure 21**). As in the previous studies, the actors portraying positive and negative dispositions were randomised between participants.

Participants viewed 36 video clips of the positive and negative characters (in pseudo random order), intermixed with 24 videos featuring the neutral character. Just as in Study 2, participants completed a task that encouraged sustained attention to the eye region. Participants were asked to watch the videos closely for eye movement. If the video featured a change of gaze direction, participants were instructed to press the spacebar as soon as the eye movement ended. If the subject saw no eye movement in the video clip, they should not press the spacebar. All video clips and subsequent photographs were presented at a pixel resolution of 800 x 542.

Figure 21

Female actors that appeared during the learning phase

Note. The 3 female actors (OG, KP and SS) are pictured here with neutral facial expressions. In the learning phase, OG and KP portrayed the positive and negative characters (randomised between participants). Actor SS only ever appeared as the neutral distractor. Actors' initials were not included in the task stimuli.

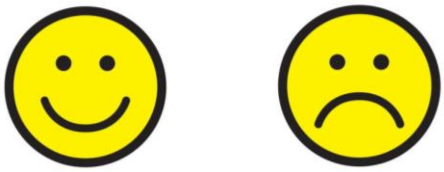
7.2.3. Test phase materials and procedure

Participants began the affective priming test phase immediately after the learning phase. Using a procedure adapted from Conte et al.'s (2018) study, participants were told that they would see brief presentations of photographs followed by target words. Participants were instructed not to react to the photographs but to indicate the emotional valence (pleasantness or unpleasantness) of the target word as quickly and accurately as possible. Responses were given by pressing the left or right arrow keys on the keyboard, which had been relabelled with positive (happy) and negative (sad) emoji-style face symbols (see **Figure 22**). For half of the participants, the left arrow was labelled as 'positive' and the right arrow as 'negative'. The reverse was true for the other half of the sample.

A fixation cross was displayed for 1000ms in the centre of the screen to signal the start of a trial. This was followed by the prime (which was presented for 200ms), then 100ms of blank screen after which the target word was presented for 1000ms, or until the participant gave a response. Participants had just 1000ms to respond, after which a tick confirmed that the participant's response was correct, while a cross and on-screen message informed participants if they were incorrect or had not responded in time.

Figure 22

Face symbols used to label the positive and negative valence response keys



Note. Face symbols indicating positive valence (left) and negative valence (right) were placed on the arrow keys of the keyboard. Assigned at random, the left arrow was 'positive' and the right arrow 'negative' for half of the participants. The other half of the sample indicated 'positive' by pressing the right arrow key, and 'negative' by pressing the left.

Participants pressed the spacebar on the keyboard to progress to the next trial, which began after a delay of 500ms. As mentioned previously, the SOA was set at 300ms to facilitate implicit automatic processing (Hermans et al., 2003; Hietanen et al., 2007). The short (1000ms) response window was retained from Conte et al.'s (2018) experiment, again to encourage the fast automatic processing of target words.

Priming stimuli: Only two primes were used in the current task; photographs of the positive and negative characters (from the learning phase) with *neutral* facial expressions. Both photographs were taken from the Warsaw set of Emotional Facial Expressions Pictures (WSEFEP, Olszanowski et al., 2015), which also provided the base images featured in the earlier learning-phase videos. During the WSEFEP validation process, 84% of assessors agreed that the 'neutral' photograph of actor OG showed a neutral facial expression, while 94% of assessors agreed on the neutrality of KP's 'neutral' photograph. Because the photographs featured neither positive nor negative facial expressions, presentation of the primes was only expected to influence target valence evaluation speeds if participants had learned the characters' social dispositions during the learning phase.

Target stimuli: When target words were presented (after a prime), participants had to indicate the valence of each word as quickly as possible. 60 target words were selected from Warriner et al.'s (2013) database of almost 14,000 valence-scored English lemmas. In Warriner et al.'s database, which included only higher-frequency words known by 70% or more of participants, words received valence scores from 1 and 9, with 1 indicating assessors' complete unhappiness, annoyance or despair and 9 indicating complete happiness, satisfaction or contentment. 14 positive and 14 negative 'personality adjectives' (words that could be used to describe people) were selected as targets (for example, 'lovable', 'honest' / 'jealous', 'repulsive') alongside 16 positive and 16 negative nouns (for example, 'sunshine', 'award' / 'disease', 'prison'). Words selected as positive targets had all received mean valence scores between 7.5 and 8.5. Negative target words had all received valence scores between 1.5 and 2.5 (see **Table 6** for target word valence and other score means and **Appendix** for the full word list). Swear words, racially discriminatory words and other words judged as potentially distressing to participants (for example, 'paedophile' and 'rapist') were not selected as targets despite their extreme valence scores.

Table 6

Affective priming task target words

	Positive target words			Negative target words		
	Adjectives	Nouns	Combined	Adjectives	Nouns	Combined
Number of words	14	16	30	14	16	30
Mean valence	7.86	7.8	7.83	2.21	2.04	2.12
Mean syllables	2.36	1.94	2.13	2.36	1.94	2.13
Mean frequency (freq. per million)	29.91	19.4	24.3	21.74	24.73	23.3
Mean word length (number of letters)	7.43	6.19	6.77	7.36	6.16	6.7

Because the number of syllables in written words is known to affect response latencies (Stenneken et al., 2007), positive and negative target words within each word class category (adjectives and nouns) were matched pairwise for syllable number. While it would have been desirable to match *all* target words for syllable number, this was not possible after applying the above-mentioned selection criteria. Word frequency (how often words are used in everyday language, measured in frequency per million words) is another factor known to influence response latencies, particularly during word recognition tasks (Polich & Donchin, 1988; Schiepers, 1980). An attempt was therefore made to also match positive and negative target words using frequencies taken from the 50 million-word SUBTLEX-US corpus (Brysbaert & New, 2009). Overall, the final selection of 30 positive and 30 negative target words differed significantly on valence score ($t_{(58)} = 99.44$, $p < .001$) but not on frequency (range 1.49 to 97.94 per million, $t_{(58)} = 0.14$, $p = 0.89$), word length ($t_{(58)} = 0.14$, $p = 0.89$) or, as mentioned, number of syllables[26]. Any differences between subtypes of target words (for example, the nouns tended to have fewer syllables and fewer letters than the adjectives) are discussed further where relevant in the results section.

After a short practice session (4 positive and 4 negative words primed by photographs of actors not featured in the learning phase), the 60 target words were presented in a single block. Because participants activated the next trial themselves, the task was self-paced, allowing participants brief opportunities for rest. The type of prime preceding the targets was pseudo-randomised, with half of the target words (within each word class and valence category) primed by the positive character's neutral photograph. The remaining words were primed by the negative character's neutral photograph. Therefore, in total, each participant evaluated 14 negative adjectives, 14 positive adjectives, 16 negative nouns and 16 positive nouns. Within each of these categories, half of the words were primed by the positive character and half by the negative character. For most participants, the affective priming test phase took around 5 minutes to complete.

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[26] *Positive target words*: mean valence = 7.83, SD = 0.22, mean frequency = 24.31, SD = 28.3, mean number of syllables = 2.13, SD = 0.68, mean word length (letters) = 6.77, SD = 1.77.
Negative target words: mean valence = 2.12, SD = 0.22, mean frequency = 23.33, SD = 26.53, mean number of syllables = 2.13, SD = 0.68, mean word length (letters) = 6.7, SD = 1.91.

7.2.4. Exclusion criteria and supplementary testing

As was the case in studies 2, 3 and 4, it was important to establish that all participants met certain criteria if their data were to be included in later analyses. It was important that participants: (1) were able to differentiate between the faces of the 3 actors, (2) had not developed explicit awareness of the characters' social cues during the learning phase, and (3) could identify disgusted, happy and neutral facial expressions accurately. It was also important to directly assess any explicit attitudinal changes toward the positive and negative characters brought about by the implicit social cues during the learning phase. Unlike in the earlier studies, participants undertook these tests several minutes after the learning phase had concluded, having completed the affective priming task in the meantime. Because of this difference, and for other reasons described below, several changes were made to the supplementary testing procedure.

To check that participants could differentiate between the faces of the characters, participants were first shown an array of 9 faces on screen (see **Figure 23**). The images, which were arranged in pseudo random order, showed the 3 actors from the learning-phase videos displaying happy, neutral and disgusted facial expressions. In every photograph, the actor's gaze was directed forward. Participants were asked 'How many different individual people are shown on screen?' (correct answer: 3).

Participants were then asked to rate the positive and negative characters (in randomised order) for 'likeability'. Study 2 quantified participants' liking of the characters using scores from four Reysen Likability Scale (Reysen, 2005) items. The current study required participants to respond to three statements on an unmarked response slider, which ranged from 'Very strongly disagree' on the left (scored as zero) to 'Very strongly agree' on the right (scored as 100). The first statement, 'This person is likeable', was retained from the Reysen Likability Scale. However, for the sake of brevity, and because Reysen item scores were highly correlated in Study 2 (correlations between 0.76 and 0.83), the remaining items were not administered. Instead, 'This person might like me' was introduced to more directly assess participants' learning of the characters' social dispositions. Participants also responded to the analogously phrased 'I might like this person' as a more direct measure of their feelings toward the characters.

Figure 23

Character differentiation array

Note. Array of faces featuring the three actors from the learning phase. Participants were asked 'How many different individual people are shown on screen?'. A correct answer of '3' indicated that participants were able to differentiate between individual actors, despite the display of different facial expressions.

To assess participants' explicit awareness of the learning phase social cues, they were then shown neutral-expression photographs of the positive and negative characters and asked for verbal responses to the following questions: (Q1) 'You have just rated these two people for likeability, and for how much they might like you. What influenced your ratings?' and, (Q2) 'Thinking about the earlier video clips featuring these two people, what can you tell me about their gaze direction and facial expressions?'. Participants were scored as having developed explicit awareness if, in answer to Q1, they referred to the previous video clips and referenced at least one 'half' of either character's social cue contingencies. For example, if a participant said that the positive character 'looked to the side and frowned', they were scored by the experimenter as explicitly aware because the positive character always looked disgusted while their gaze was averted.

Q2 made participants explicitly aware that there may have been a link between characters' gaze directions and facial expressions. Participants who correctly identified social disposition cues following Q2 were not excluded for developing explicit awareness. While these participants may have identified parts of the social cues when prompted, they had not consciously used this information when rating the characters for likeability (as established by Q1). The number of participants who correctly recalled characters' cues at this stage is, however, presented in the results section. While participants' explicit awareness would ideally have been tested immediately following the learning phase, the awareness questions were asked at this point to avoid drawing participants' attention to the social cues prior to the affective priming test phase.

Finally, to check that participants could identify the task-relevant facial expressions, participants were shown images of the positive and negative character actors (in random order) displaying 'disgusted', 'happy' and 'neutral' facial expressions. For each of the 6 images, participants were asked to select the word that best described the actor's emotion. The options were 'surprise', 'happiness', 'sadness', 'neutral', 'disgust' and 'fear'.

7.2.5. Additional assessments

Participants also completed standardised assessments of self-reported autistic traits, receptive vocabulary and non-verbal (fluid) intelligence. As in the previous studies, participants completed a computerised version of the AQ-S (Hoekstra et al., 2011) to quantify self-reported autistic traits. Receptive vocabulary was then assessed using the Receptive One-Word Picture Vocabulary Test-4 (ROWPVT, Martin & Brownell, 2011). Participants were asked to identify the correct picture, from a choice of four, that best matched a word spoken by the experimenter. No verbal responses were required from participants, though in practice all participants answered verbally by stating the number associated with their chosen picture. Finally, Raven's Standard Progressive Matrices (Raven et al., 2000) was used to assess non-verbal reasoning/fluid intelligence. Each item contained a pattern or set of pictures with one part removed. Participants were asked to identify the correct image, from a choice of up to eight, that completed the picture set. Once again, no verbal responses were required. Raw scores from all assessments are presented in the results section unless otherwise specified.

7.3. Results

7.3.1. Exclusion criteria data reduction

Explicit awareness of social cues: To assess whether participants had developed explicit knowledge of the positive and negative characters' social cues, they were asked what had influenced their likeability ratings (Q1). As in the previous studies, participants were scored as having developed explicit awareness if they referred to the earlier video clips and unambiguously identified at least one 'half' of either character's social cue contingencies. Just one (TD) participant showed evidence of explicit awareness in their response to Q1 and their data were excluded from subsequent analyses.

In response to Q2 ('Thinking about the earlier video clips… what can you tell me about their gaze direction and facial expressions?'), 14 of the remaining 83 participants (17%) correctly described at least one element of a social cue seen in the learning-phase videos. There was no significant difference in AQ-S score ($t_{(73)} = 1.55$, $p = .13$) between the participants who were ($M = 62.71$, $SD = 11.22$) and were not ($M = 69.59$, $SD = 15.7$) able to recall social cue details when prompted. Participants who recalled elements of the social cues following Q2 were not excluded from the final sample. As established by Q1, any knowledge of social cues had not consciously influenced their character likeability ratings.

Facial expression identification: Participants were asked to identify the facial expressions shown in photographs of the positive and negative character actors. There were 6 images in total in which 'disgust', 'joy' and 'neutral' facial expressions were displayed. Participants were excluded if they could not identify at least one example of each facial expression correctly. One (autistic) participant was excluded for this reason. All other participants identified at least 5 of the 6 facial expressions correctly.

Face differentiation: Participants were shown an array of the learning-phase actors' faces (see Figure 23) and were asked 'How many different individual people are shown on screen?' (correct answer: 3). 75 of the 82 remaining participants (91%) answered correctly, with the remaining participants giving answers of 4, 6 or 9. Those who answered incorrectly were excluded from subsequent analyses because it was uncertain whether they had successfully differentiated between the positive and negative characters' faces when viewing the learning-phase videos.

After applying the exclusion criteria, data from 75 participants remained (33 males, 39 females, 3 non-binary). This sample included 23 participants (8 males, 13 females, 2 non-binary) who had reported an autism diagnosis. The two groups differed significantly on AQ-S score (ASD group mean = 83.78, SD = 10.1, TD group mean = 61.46, SD = 11.53, $t_{(73)}$ = 8.02, p < .001). The groups also differed significantly on age (ASD mean = 32.69 years, SD = 14.18, TD mean = 23.88 years, SD = 7.25, , $t_{(73)}$ = 3.57, p < .001), Raven's matrices fluid intelligence (ASD mean = 53.96, SD = 4.05, TD mean = 51.75, SD = 4.22, , $t_{(73)}$ = 2.11, p = .04) and ROWPVT vocabulary (ASD mean = 174, SD = 7.36, TD mean = 164.02, SD = 10.87, , $t_{(73)}$ = 4.01, p < .001). Because the ASD and control groups differed significantly on these additional variables, two sets of analyses were conducted. The following section analysed data from *all* non-excluded participants. The same analyses are later presented using data from an age- and fluid intelligence-matched sample.

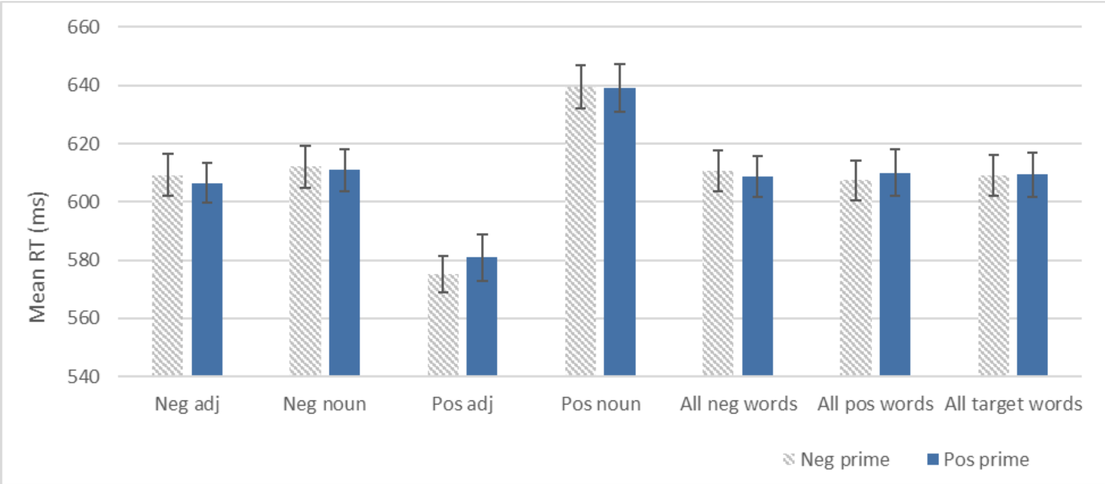
7.3.2. Affective priming: All participants

Participants were presented with primes ('neutral expression' images of either the positive or negative actor) followed by target words. Participants indicated the valence of each target word as quickly as possible, with just 1000ms available to respond. Response accuracy was high, with errors or time-outs occurring on just 5.9% of trials. Individual participants achieved overall response accuracies of 82% to 100% (M = 94%). Similar to Conte et al. (2018) and Jellema et al. (2011), only correct responses that fell within 2.5 SDs of each word category's mean RT were retained for the following analyses. 142 data points were removed for this reason (3.16% of all responses). See **Figure 24** for valence decision RTs, split by prime type and target word category.

TD participants were initially predicted to show evidence of a valence congruence effect, a negative priming effect (Conte et al., 2018) or, potentially, both effects. If an autism-related disconnect exists between implicitly learned social information and its subsequent influence on cognition, these priming effects were predicted to be reduced or absent in the ASD group.

Figure 24

Valence decision reaction times, split by prime type and target word category



Note. Pooled data from all participants. Mean reaction times, split by target word category and prime type (positive or negative character photographs). Positive and negative primed reaction times were closely matched in every individual and every combined target word category. Bars show SEM.

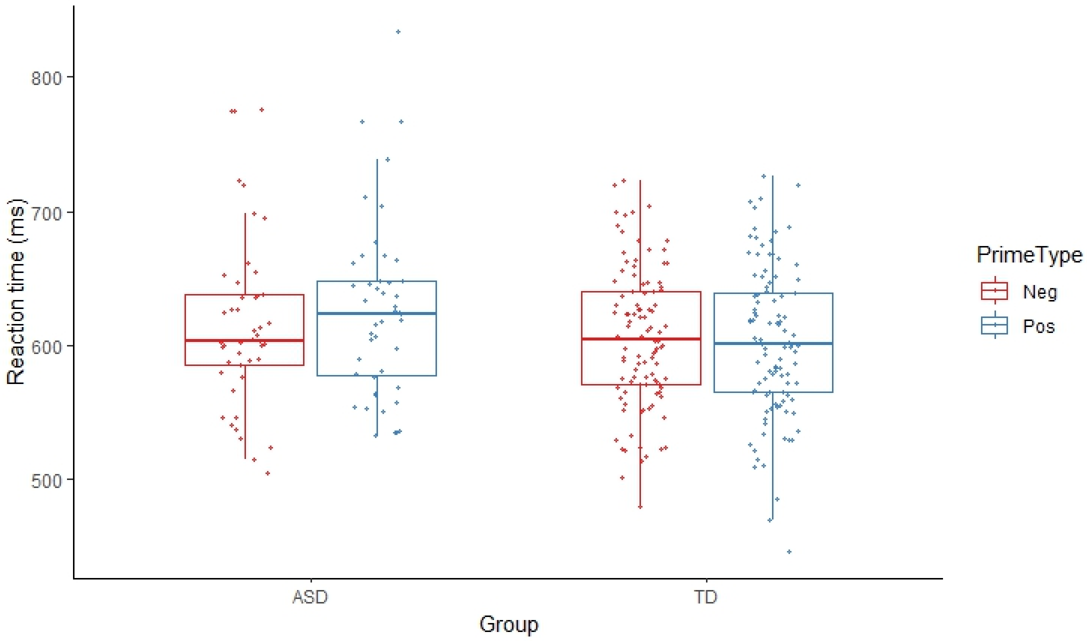
Congruence and negative priming effects: A 2x2x2 mixed design ANOVA was conducted to test the effect of group (ASD or TD), prime type (positive or negative character) and target word valence (positive or negative) on participants' valence decision RTs. A significant interaction between prime type and target word valence could indicate a congruence effect, whereas a significant main effect of prime type could indicate a general 'negative priming effect' (the negative character inhibiting responses to all targets). The ANOVA results, however, revealed no significant main effects of group ($F_{(1,73)} = 1.67$, $p = .2$), prime type ($F_{(1,73)} = 1.51$, $p = .22$) or target valence ($F_{(1,73)} = 0.12$, $p = .73$). No two- or three-way interactions approached the level of statistical significance, with one exception.

There was a significant interaction between group and prime type ($F_{(1,73)} = 7.93$, $p = .006$). For the control group, RTs did not differ significantly between positive character-primed trials (M = 602.07ms, SD = 52.85) and trials primed by the negative character (M = 605.64ms, SD = 48.58, $t_{(51)} = 1.4$, $p = .17$). Autistic participants took significantly longer to respond to positive character-primed targets (M = 625.81ms, SD = 63.24) than to negative character-primed targets (M = 616.73ms, SD = 62.2, $t_{(22)} = 2.6$, $p = .016$). See

Figure 25. There was, however, no evidence that priming using neutral-expression images of the learning-phase characters produced a congruence effect. Also, against predictions, the negative (anti-social) character did not inhibit target valence decision speeds (either generally, or during congruent trials specifically).

Figure 25

Valence decision reaction times, split by group and prime type



Note. Tukey box plot showing valence decision RTs for all target words, split by group (ASD and TD) and prime type (neutral expression photographs of the positive [Pos] or negative [Neg] character). Autistic participants, but not TD participants, took significantly longer to respond to positive character-primed targets than to negative character-primed targets.

Paired-samples t-tests were also conducted to determine whether the positive and negative primes had caused significant differences in reaction speeds in any of the individual target word categories (negative adjectives, negative nouns, positive adjectives and positive nouns). Individual tests were conducted because word characteristics (including frequency and length) were expected to influence RTs but were not closely controlled for *between* individual word categories. Only once words were combined into 'positive targets' and 'negative targets' were all word characteristics (except valence) closely matched. The t-tests, even without Bonferroni correction, revealed no significant prime-related RT differences in any of the individual target word categories.[27]

7.3.3. Affective priming: Age and intelligence-matched sample

A new subset of participants was created in which the autistic and control groups *were* matched closely for age and fluid intelligence. This subset contained data from 20 autistic participants (8 males, 10 females, 2 non-binary, mean age = 28.6 years) and 32 non-autistic participants (17 males, 14 females, 1 non-binary, mean age = 26.4 years). The two groups differed significantly on AQ-S score (ASD group mean = 84.25, SD = 10.15, TD group mean = 63.81, SD = 12.03, $t_{(50)} = 6.32$, $p < .001$), but not on age (ASD mean = 28.6 years, SD = 9.81, TD mean = 26.41 years, SD = 8.29, , $t_{(50)} = 0.86$, $p = .39$), fluid intelligence (Raven's matrices, ASD mean = 53.4, SD = 4.01, TD mean = 52.63, SD = 3.44, , $t_{(50)} = 0.74$, $p = .46$) or, by the smallest of margins, receptive vocabulary (ROWPVT, ASD mean = 173.15, SD = 6.79, TD mean = 167.94, SD = 10.3, , $t_{(50)} = 2$, $p = .0504$). A Fisher's exact test ($p = .49$) also indicated no significant difference in sex composition between the new ASD and control groups.

Congruence and negative priming effects: Again, a 2x2x2 mixed design ANOVA tested the effect of group, prime type (positive or negative character) and target word valence (positive or negative) on participants' RTs. The results again revealed no significant main effects of group ($F_{(1,50)} = 0.77$, $p = .39$), prime type ($F_{(1,50)} = 0.07$, $p = .79$) or target valence ($F_{(1,50)} = 0.03$, $p = .86$). The previously significant interaction between group and prime type remained significant ($F_{(1,50)} = 6.103$, $p = .017$). As before, autistic participants took longer to respond to positive character-primed targets (M = 612.65ms, SD = 44.59) than to negative character-primed targets (M = 603.65ms, SD = 45.27, $t_{(19)} = 2.5$, $p = .022$). No other two- or three-way interactions approached the level of statistical significance. Therefore, the analysis again revealed no evidence of a congruence effect or any form of negative priming effect.

[27] T-tests indicated that primes did not cause a significant difference in RTs in any of the individual target word categories. Negative adjectives: $t_{(74)} = 0.66$, $p = .51$. Negative nouns: $t_{(74)} = 0.24$, $p = .81$. Positive adjectives: $t_{(74)} = -1.12$, $p = .27$. Positive nouns: $t_{(74)} = 0.087$, $p = .93$.

7.3.4. Multilevel analyses: Congruence and negative priming effects

The current study was designed to test whether implicitly learned social information influenced subsequent cognitive processes and whether the magnitude of this effect correlated negatively with autistic traits. It was proposed that either a congruence effect would be present or that the negative prime would inhibit participants' response speeds. However, neither effect was detected at a group level.

As identified in studies 2, 3 and 4, task data had the potential to be hierarchically organised. Prime-related effects may have been nested within actor conditions (i.e., the particular actors portraying the positive and negative characters may have influenced priming effects). Effects may also have been nested within participant sex.[28] Multilevel analyses were therefore conducted that could identify hierarchically organised data and evaluate correlational trends within it. All (non-excluded) participants' data were included in the following multilevel analyses.

Congruence effect: A derived measure of 'congruence difference' (CD) was calculated by subtracting each participant's mean 'congruently primed' RT from their mean 'incongruently primed' RT. A positive CD would indicate that a participant responded more quickly to congruent trials (e.g., positive prime followed by positive target word) than to incongruent trials (e.g., positive prime followed by negative word). A negative CD would indicate that a participant evaluated the valence of the target word more quickly after an incongruent prime was shown.

The data were first fitted to a baseline model (*intercept_only*) that predicted CD from just the intercept. Next, data were fitted to a *random_intercept_actor* model that allowed regression line intercepts to vary by the actor who portrayed the positive character. Comparing the two models revealed that *random_intercept_actor* fitted the data no better than the baseline model (likelihood ratio = 0.13, p = .72), suggesting that CD was not nested significantly within actor conditions. This procedure was repeated, creating another model that allowed the intercept to vary by participant sex

[28] Similar to studies 2, 3 and 4, priming effects may also have been influenced by whether or not the participant was the same sex as the characters they had viewed ('same_sex'). However, because only female actors/characters were used in the current study, any nesting of data within 'participant sex' would necessarily be equivalent to nesting of data within 'same_sex' (i.e. every female participant was the same sex as the characters they viewed, while all male and non-binary participants were not the same sex as the characters they viewed).

(*random_intercept_sex*). Again, no evidence of data nesting was found (likelihood ratio = 9.55e-08, p = .9998). Allowing the intercept to vary by participant group (ASD vs TD) also resulted in no data fit improvements (likelihood ratio = 9.89e-08, p = .9997), supporting the result of the earlier group analysis.

As CD data were not organised hierarchically, a multiple linear regression was conducted to predict CD from self-reported autistic traits (AQ-S), fluid intelligence (Raven's matrices), vocabulary (ROWPVT) and participants' age (in years). Of primary interest was the relationship between AQ-S and CD. Overall, the model was a poor fit to the data ($F_{(4,70)}$ = 1.32, p = .27) with none of the variables significantly predicting CD. Of the 4 predictors, only fluid intelligence approached the level of statistical significance (slope coefficient β = 1.35, t = 1.94, p = .057).

Negative priming effect: 'Prime difference' (PD) was calculated by subtracting each participant's mean positive character-primed RT (across all target words) from their mean negative character-primed RT. A positive PD indicated that participants took longer to react after the negative prime (i.e., that anti-social primes inhibited reaction speed), while a negative PD indicated that participants took longer to respond following the pro-social prime.

As before, data were first fitted to a baseline model (*intercept_only*). Next, data were fitted to a *random_intercept_actor* model that allowed regression line intercepts to vary by the actor who portrayed the positive character. This model fitted the data no better than *intercept_only* (likelihood ratio = 8.44e-08, p = .9998), suggesting that PD data was not nested within actor conditions. The procedure was repeated, creating models that allowed the intercept to vary by participant sex (*random_intercept_sex*) and participant group (*random_intercept_group*). Again, no evidence of data nesting was found (*random_intercept_sex*: likelihood ratio = 6.68e-08, p = .9998, *random_intercept_group*: likelihood ratio = 2.8, p = .094). As PD data were not organised hierarchically, a multiple linear regression was conducted to predict PD from autistic traits (AQ-S), intelligence (Raven's matrices), vocabulary (ROWPVT) and age. Again, the model was a poor fit to the data ($F_{(4,70)}$ = 1.34, p = .27) with none of the variables significantly predicting PD.

7.3.5. Character likeability ratings

Participants were asked to rate the positive and negative characters for 'likeability' using three items: 'This person is likeable', 'This person might like me' and 'I might like this person'. Unlike in Study 2 (where participants rated the characters immediately following the learning phase), participants did not answer the likeability questions until after the completion of the affective priming test phase. A scale reliability analysis, conducted using R package *psych* (Revelle, 2021), indicated good to excellent internal consistency for the likeability items (Cronbach's alpha = 0.91). Each participant's mean score from the three items was used in the following analysis. Study 2 found that implicit learning from identical facial cues influenced participants' likeability ratings, with the positive character viewed as more likeable than the negative character. However, in the current study, a paired samples t-test found that participants' ratings of the positive character (M = 58.68, SD = 16.26) did not differ significantly to their ratings of the negative character (M = 58.49, SD = 15.57, $t_{(74)}$ = 0.12, p = .9). Separate t-tests conducted for the autistic ($t_{(22)}$ = 0.58, p = .56) and TD groups ($t_{(51)}$ = 0.51, p = .61) also revealed no significant differences between positive and negative character likeability ratings.

As in the previous studies, 'likeability difference' (LD) was then calculated by subtracting a participant's likeability rating of the negative character from their rating of the positive character. In Study 2, a small but significant positive correlation was found between AQ-S and LD. In the current study, however, no significant correlation between AQ-S and LD was found ($r_{(73)}$ = -0.094, p = .42). As before, multilevel analyses were undertaken to rule out nesting of LD data by actor condition, participant sex and group (ASD vs TD). None of the models fitted the data better than the baseline model (*intercept_only*), indicating no evidence of hierarchical organisation.[29] A multiple linear regression was therefore conducted to predict LD from autistic traits (AQ-S), intelligence (Raven's matrices), vocabulary (ROWPVT) and age. The model was a poor fit to the data ($F_{(4,70)}$ = 0.78, p = .54) with none of the variables significantly predicting LD.

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[29] A *random_intercept_actor* model, which allowed regression line intercepts to vary actor condition, fitted the data no better than the baseline *intercept_only* model (likelihood ratio = 7.87e-08, p = .9998). The procedure was repeated, creating models that allowed the intercept to vary by participant sex and participant group. No evidence of data nesting was found (*random_intercept_sex*: likelihood ratio = 6.72e-08, p = .9998, *random_intercept_group*: likelihood ratio = 7.6e-08, p = .9998).

7.3.6. Bayesian analyses

The previous analyses detected no significant effects of congruence or prime type on valence decision reaction times, and no significant effect of the learning phase social cues on character likeability ratings. As recommended by Dienes (2014), Bayes factors (*BF*) were calculated that could quantify support for the null hypotheses (for example, that primes had no effect on RTs) or indicate, in each case, whether the data were insufficiently sensitive to detect an effect. Bayes factors could also provide support for the 'alternative hypothesis' (e.g., that primes *did* affect RTs), despite the previous null findings. Broadly speaking, a $BF \leq 1/3$ would support the null hypothesis, a $BF \geq 3$ would support a significant effect (in line with the alternative hypothesis) and a *BF* lying between 1/3 and 3 would indicate data insensitivity (Dienes, 2014).

Congruence effect: Jellema et al. (2011) reported a mean RT difference between affectively congruent and incongruent conditions (Experiment 2) of 30ms (SD not reported but estimated at 20ms). Using R package *Bayesplay*, these figures were used to define the alternative prior distribution. The null prior was set as a normal distribution with a mean RT difference of 0. A BF_{10} of 0.28 was calculated for the current study's data, indicating support for the null hypothesis that no congruence effect was present.

Negative priming effect: Conte et al. (2018) reported that adult participants took, on average, 15.78ms (SD = 13.36) longer to identify congruent emotional facial expressions following an angry face (as opposed to a happy face) prime. These figures defined the alternative prior distribution, with the null prior set as a normal distribution with a mean RT difference of 0. A BF_{10} of 0.41 indicated that the current study's data better supported the null hypothesis than the alternative, but that data insensitivity ruled out strong support in either direction.

Likeability difference: Study 2 found that, following 36 exposures to the learning phase cues, participants rated the positive character as more likeable than the negative character (mean LD = 5.9, SD = 18.51). These figures defined the alternative prior distribution, with the null prior again set as a normal distribution with a mean of 0. A BF_{10} of 0.67 indicated that Study 5's data better supported the null hypothesis than the alternative, but that the data were insensitive. In all three cases, therefore, Bayesian inference did not contradict the findings of the previous analyses.

7.3.7. Vocabulary

Given the well-supported association between implicit learning and language development (see section 1.3), the current study's measures of implicit learning were initially predicted to correlate positively with participants' vocabulary. Because language difficulties are common in autism (Kwok et al., 2015), a negative correlation might be expected between autistic traits and vocabulary, when controlling for age and fluid intelligence. A multiple linear regression was conducted to predict vocabulary (ROWPVT raw score) from congruence difference, prime difference, likeability difference, self-reported autistic traits (AQ-S), fluid intelligence (Raven's matrices) and participants' age. Overall, the model was a good fit to the data ($F_{(6,68)} = 6.98$, $p < .001$) with an R^2 0.38. Participants' age (slope coefficient $\beta = 0.33$, $p = .0034$) and fluid intelligence ($\beta = 0.71$, $p = .0081$) were found to significantly predict vocabulary. However, congruence difference, prime difference, likeability difference and autistic traits were not significant predictors of ROWPVT score. Of the 'non-significant' predictors, only AQ-S ($\beta = 0.14$, $p = .064$) approached the level of statistical significance.

7.4. Discussion

In Study 2, an implicit learning phase that featured dynamic facial cues caused TD participants to like the positive character more than the negative character. In the current study, a near-identical learning phase was followed by an affective priming task, in which neutral-expression photographs of the two characters served as primes. Evidence of a congruence effect and/or a negative priming effect was predicted for TD participants. However, if an autism-related 'disconnect' exists between implicit learning and its subsequent influence on cognition, it was predicted that any priming effects seen in the TD participants would be reduced, or absent, in the autistic participants.

Following group-level analyses, multilevel modelling and Bayesian analyses, the current study produced no evidence of a congruence effect, or of a negative priming effect, in either set of participants. The only significant priming effect detected was in the ASD group. Autistic participants took significantly longer to respond to positive character-primed targets than to negative character-primed targets (regardless of target valence). Possible explanations for this unpredicted finding are presented later in the Discussion. Of primary concern though, was whether the current study's learning phase caused participants to favour the positive character over the negative character (as they had in Study 2). Because successful implicit social learning during the learning phase was fundamental to any subsequent affecting priming effect, it is discussed here first.

7.4.1. Did learning occur during the learning phase?

As noted above, any priming effects in the current study necessarily relied upon participants implicitly learning the characters' social dispositions during the learning phase. Furthermore, priming effects were contingent upon participants attaching a positive valence to the pro-social character and a negative valence to the anti-social character. However, it remains uncertain whether these necessary steps occurred in Study 5. After all, unlike those in Study 2, Study 5's participants did not later rate the positive character as significantly more likeable than the negative character.

Study 5's learning phase was almost identical to that used in Study 2, but with several minor alterations that should have *improved* implicit social learning. Unlike Study 2, which was conducted online, the current study's participants viewed stimuli in laboratory conditions on a large (27 inch) high-definition screen. In the absence of distractions, and with a clear view of the stimuli, implicit learning opportunities should have been optimised. Participants also viewed video clips featuring only those actors who produced reliable 'likeability differences' in Study 2, again optimising opportunities for learning. Given the demonstrated efficacy of Study 2's learning phase (and of similar learning phases used by Hudson et al., 2012 and Macinska, 2019), plus the finding that a significant (albeit unexpected) priming effect *was* later detected in the autistic participants, it seems probable that social learning did occur in the current study. If Study 5's learning phase *did* foster implicit learning, there appear to be two main possibilities for the later absence of an explicit likeability difference.

Likeability item insensitivity?: Firstly, the statements used to assess character likeability were different to those used in Study 2. It is possible that Study 5's likeability items did not detect a genuine discrepancy between participants' attitudes towards the characters. While item insensitivity is a possibility, it seems unlikely. In Study 2, participants' liking of the characters was quantified using four items from the Reysen Likability Scale (Reysen, 2005), the scores from which were highly correlated. Study 5 re-used one of the Reysen items ('This person is likeable') alongside two new items ('This person might like me' and 'I might like this person'). This new three-item scale had excellent internal consistency (Cronbach's alpha = 0.91), suggesting that responses to the two new items correlated highly with the original Reysen item which, in turn, correlated highly with the other Reysen items used in Study 2. If the current study were to be repeated, the reliability and validity of the new items should be tested systematically. However, indirect evidence suggests that Study 5's likeability statements were probably able to detect genuine differences in participants' attitudes towards the characters, *if* they existed at the time of testing.

Interference from the priming task?: The second explanation for the absence of a significant explicit likeability difference relates to an important procedural change between studies 2 and 5. In Study 2, likeability ratings were taken immediately after the learning phase, when implicit representations of the two characters (as pro- and anti-social) were likely to be at their strongest. In Study 5, however, participants did not rate the characters for likeability until after they had completed the affective priming task. This task featured 30 presentations of each character displaying a neutral facial expression (alongside highly positively or negatively valenced words) and took participants around 5 minutes to complete. Evidence, presented below, suggests that engaging in such a task could have interfered with any implicit representations of the characters acquired previously.

Multiple studies have shown that implicitly learned information is typically consolidated in the memory in the hours (or even days) after learning takes place (Janacsek & Nemeth, 2012; Meier & Cock, 2014; Nemeth & Janacsek, 2011). Such studies often require participants to learn sequences implicitly (for example, using SRT tasks), which are then re-tested at various intervals after the initial learning phase. In such studies, improved performance in subsequent tests is indicative of successful memory consolidation. However, exposing participants to information that conflicts with their earlier learning is known to disrupt memory consolidation processes. This 'retroactive interference' (Alves & Bueno, 2017) reduces access to implicitly acquired knowledge and adversely affects subsequent test performance (Eakin & Smith, 2012; Lustig, Cindy &

Hasher, 2001). Li and Morton (2019), for example, found that participants' retention of a SRT task sequence was reduced significantly if they learned a second sequence five minutes after the first. In Study 5, the repeated presentations of both characters' neutral faces (throughout the priming task) may have interfered retroactively with implicit knowledge of the characters' pro- and anti-social dispositions. While this is a plausible explanation for Study 5's null likeability findings, a comparable study by Macinska (2019, see section 4.1 for a detailed description) produced contrasting results.

Following Macinska's learning phase (which was similar to that used in the current study), participants answered a series of 'awareness' questions and completed a 'morph composite evaluation' task before they rated the characters for likeability. Unlike in Study 5, Macinska *did* find a significant difference in character likeability ratings in both the TD and autistic participants. However, as mentioned in section 4.1.3, Macinska's awareness questions drew attention to the learning phase cues. Participants may therefore have gained an explicit understanding of the characters' dispositions before the morph judgement task and, importantly, before rating the characters for likeability. Research using non-social implicit learning tasks has shown that, when participants become explicitly aware of underlying structures, not only does their task performance suddenly improve (Esser et al., 2022; Haider et al., 2011; Lustig, Clarissa et al., 2022) but they also express greater certainty about their correct responses (Haider et al., 2011; Persaud et al., 2007). There are currently no equivalent findings for implicit *social* learning tasks. However, if Macinska's questions did promote explicit awareness in participants, this awareness may have similarly enhanced social learning, rather than interfering with it. This mechanism could explain the difference between Macinska's (2019) findings and those of the current study.

Researchers have also yet to study the effect of retroactive interference on implicit *social* learning specifically, making it an important area for future investigation. Because retroactive interference is known to impair implicit learning in other domains, it would be surprising if social learning were immune from its effects. As the disparate results of studies 2 and 5 seem to indicate, it may be important to factor retroactive interference into the design of future implicit learning experiments. It remains a possibility that learning *did* occur for the majority of participants in the current study's learning phase, though only the ASD group showed evidence of it during the priming task. Interference from that priming task may, however, have nullified any difference in the subsequent explicit character likeability ratings.

7.4.2. Affective priming effects

The current study included the first known attempt to use neutral faces (after an implicit learning phase) as affective primes. However, as stated previously, there was no evidence of the predicted 'valence congruence' or 'negative priming' effects in either set of participants. Because none of the participants rated the characters for likeability immediately after the learning phase, it is difficult to determine why the predicted priming effects were not detected. It is possible (though seemingly improbable) that no social learning took place during the learning phase. In the absence of implicit social learning, positive or negative valences would not have been attached to the characters, making their neutral faces ineffective as primes.

A second (and perhaps more likely) possibility is that learning did occur, but that the resulting implicit social representations exerted little to no influence on priming task responses. It is possible that, even if the current study's learning phase had produced similar results to Study 2's, the valences attached to the characters may not have differed sufficiently from one another to elicit detectable priming effects. In Study 2, participants liked the positive character (M = 59.54, SD = 15.6) significantly more than the negative character (M = 53.64, SD = 16.5). Mean character likeability ratings only differed by around 10% though, and both ratings were positive (above 50, see section 4.3.2). Essentially, while there was considerable variation amongst responses, Study 2's participants tended to form a positive opinion of both characters but demonstrated a slightly greater preference for the pro-social character. If this effect had been replicated in Study 5, it would not have been optimal for a priming task. Affective priming studies typically attempt to maximise priming effects by selecting primes that are at opposing ends of the valence spectrum. Following the minor alterations made to the current study's learning phase (see the previous section), it was initially predicted that Study 5's participants would like the positive character and *dislike* the negative character. However, if the likeability difference had remained small, and especially if both characters became positively valenced, the neutral-faced primes would be expected to exert little (if any) influence on valence decision response speeds.

This second explanation for the absence of predicted priming effects seems plausible. However, if the current study's participants attached similar valences to the two characters, why did the ASD group take longer to respond to positive character-primed targets than to negative character-primed targets? No equivalent findings were reported by Hudson et al. (2012) and Macinska (2019), the only other researchers known to have used a similar learning phase. Indeed, to the author's knowledge, Study 5 includes the first demonstration that a (potentially) positive prime can *inhibit* valence decision response speeds in autistic individuals. This is a finding that remains difficult to interpret or explain.

Several task-relevant factors could be excluded as likely contributors to the 'positive character inhibition' effect. As was the case in studies 2, 3 and 4, the actors portraying the pro- and anti-social characters were randomised between participants. Therefore, idiosyncratic qualities of the facial stimuli were unlikely to inhibit participants' responses in the directional manner observed. This conclusion is supported by multilevel analyses which showed that allowing intercepts to vary by 'actor condition' did nothing to improve model accuracy (see section 7.3.4). With Study 5's exclusion criteria in place, it is similarly unlikely that 'positive character inhibition' was caused by difficulties in differentiating between the characters or in interpreting their facial expressions accurately. Based on the findings of studies 2 and 3, it is also doubtful that autistic participants attached a negative valence to the positive (pro-social) character, which then inhibited their response speeds. A consistent finding from the previous studies was that higher autistic traits were associated with more accurate learning from the undetected social cues.

The inhibitory influence of the positive character *might*, however, relate to an autism-associated atypicality in the early stages of implicit emotion processing. As described in section 7.1.1, affective valence is processed rapidly and automatically and provides a near-immediate influence on other cognitive processes (Aguado et al., 2012; Neta et al., 2011; Stone & Valentine, 2004; Todorov et al., 2011). It has long been known that valenced stimuli influence the magnitude of the startle response (Vrana et al., 1988). Negative stimuli rapidly prime defensive responses, potentiating the startle reflex, whereas positive stimuli typically attenuate it (Anokhin & Golosheykin, 2010).

Wilbarger et al. (2009) showed autistic and TD adult participants images with positive, negative and neutral valences. After each image, participants were exposed to a sudden loud noise and the magnitude of their eyeblink startle response recorded. In contrast to the typical pattern of startle modulation exhibited by the control group, both positive and negative images potentiated the startle reflex in the autistic participants. Higher-order measures of image valence appraisal, including an explicit self-report measure, were similarly accurate in both sets of participants. It was therefore suggested that when autistic individuals viewed the positively-valenced images they *"may cognitively appraise them as positive, but experience a low-level defensive motivational (somatic) response. Such ambiguity may render positive stimuli unreliable, useless, or even noxious*" (Wilbarger et al., 2009, p. 1329).

Wilbarger et al.'s study identified an interesting autism-related atypicality in the processing of positive stimuli. However, the positive images did not prime the defensive response (startle reflex) to a greater extent than the negative images. Therefore, while Wilbarger et al.'s finding may be of some relevance to the current study's 'positive character inhibition' effect, it cannot fully explain it. As discussed in the previous chapter, it may be the case that elements specific to the learning phase cues (which were highly 'eye region' dependent), or the on-screen (versus 'real life') presentation of social signals, may also have contributed to the effect in ways that are yet to be determined.

As the 'positive character inhibition' effect remains difficult to account for, a sensible next step would be to verify that it is a genuine, replicable effect that is worthy of further investigation. Even within the current study, the effect was not detected consistently using different methods of data analysis. While group level (ANOVA) analyses indicated that autistic participants responded more slowly following the positive prime, no such effect was detected when 'prime difference' was investigated using multilevel models.[30] It is therefore recommended that this experiment is re-run, both directly replicating Study 5's method and using a procedure that uses alternative faces and target words.

[30] As explained in section 7.3.4, a positive prime difference (PD) indicated that a participant took longer to respond after the negative prime (i.e., that the negative/anti-social prime inhibited response speed). A negative PD indicated that a participant took longer to respond following the positive/pro-social prime. Allowing regression line intercepts to vary by participant group (ASD or TD) did not improve the model's accuracy, indicating that there was no significant nesting of PD data within participant groups.

Such manipulations might determine whether positive character inhibition was an artifact of Study 5's particular methodology or, indeed, its particular set of participants. In a similar vein, if this experiment were to be repeated, it is recommended that a subset of participants complete the explicit likeability questions immediately following the learning phase. Such participants would then have to be excluded from the remainder of the study, as these questions are likely to promote explicit awareness of the learning phase cues. However, this procedure would re-test the implicit learning phase's efficacy without retroactive interference from the priming task.

7.4.3. Summary and conclusions

Following a learning phase similar to that used in Study 2, the current study's autistic and TD participants completed an affective priming task, in which 'neutral expression' images of the characters were presented as primes. Study 5 found no evidence of a valence congruence effect, or of a negative priming effect, in either participant group. In the current study, priming effects relied on successful implicit social learning taking place during the learning phase. However, because no differences in later character likeability ratings were detected, the extent to which this necessary step occurred remains uncertain. The only significant priming effect detected was in the autistic participants, who took longer to respond to positive character-primed targets than to negative character-primed targets. The mechanism behind this unexpected 'positive character inhibition' remains uncertain, though it might relate to an autism-associated atypicality in the automatic processing of positively valenced stimuli (Wilbarger et al., 2009).

Hudson et al. (2012) and Macinska (2019) found that implicit learning from similar learning phases influenced participants' responses on gaze-cuing and morph judgement tasks. Both studies concluded that higher autistic traits were associated with task performances consistent with reduced learning. While the final study in this thesis perhaps raised more questions than it answered, it was at least consistent with studies 2, 3 and 4 in one important aspect: No evidence was found that autism (or increased autistic traits) related to a reduced capacity for implicit social learning. Studies 2-4 found that autistic traits correlated positively with learning, as long as attention was constrained to the characters' eyes. In Study 5, the only empirical indication that any form of learning occurred (the presence of the ‘positive character inhibition’ effect) was found in participants with a previous ASD diagnosis. If this effect can be replicated, autistic individuals’ seemingly atypical cognitive response to implicit social learning could prove a worthy topic for further investigation.

Chapter 8. General discussion

The principal goal of this thesis was to contribute to our understanding of implicit learning and its relationship to autistic symptomatology. Five studies investigated how two subcategories of implicit learning (statistical learning and social learning) related to autistic traits and to clinical ASD diagnoses. This final chapter provides a closing discussion of all five studies. The following sections present *aide memoire* summaries of the studies and their contributions to academic knowledge. This chapter also provides an opportunity to discuss findings from two highly relevant studies that were published after research for this thesis had been completed. These studies provide additional insights into implicit learning in autism which are integrated with this thesis' findings later in the discussion. Methodological limitations are also discussed alongside suggestions for future research.

8.1. Summary of the studies

8.1.1. ISL in young, lower-functioning autistic children (Study 1)

While autistic and TD participants have been shown to perform similarly on a wide range of implicit statistical learning (ISL) measures, younger and lower-functioning autistic participants were often missing from these studies. It is therefore unknown whether these children share a reduced ability to learn implicitly (see section 1.7 for a summarised rationale). A novel touchscreen statistical learning task was created for Study 1, aimed specifically at this participant group. The novel task successfully detected the effects of implicit learning. Children who had developed no explicit awareness of the task's underlying structure reacted faster to targets following the high-probability cue than the low-probability cue. However, the ISL task, though designed to be as simple (and as child-friendly) as possible, proved inaccessible for many of the lower-functioning autistic participants. This difficulty, combined with the sudden implementation of COVID-19 social distancing measures, meant that insufficient data were collected to address Study 1's original research questions.

While Study 1 was not able to establish whether an ISL deficit exists within younger, lower-functioning autistic children, useful discoveries were made that could inform future research on this topic. Stimuli sequences based on transitional probabilities (as opposed to deterministic sequences disguised by random stimuli) were used to increase the ecological validity of the task. These non-deterministic sequences successfully fostered implicit learning in young children and can be recommended for use in future research. Study 1 also introduced an effective new method for recording reaction speeds. Reaction time variance was shown to be lower for 'finger lifts' than for 'target swipes'. This outcome suggests that recording 'lift RTs' may help reduce the influence of autistic participants' sensorimotor differences when using similar touchscreen interfaces.

In addition to the effects of implicit learning, reactive inhibition appeared to influence children's response times significantly in Study 1. This observation highlighted the importance of mitigating fatigue effects in future ISL studies. In particular, if tasks attempt to detect the effects of violating probabilistic 'rules' learned previously, the final disruption block should be equal in length to the learning-phase blocks.[31] This precaution would prevent reactive inhibition from lengthening mean RTs to a greater extent in the disruption block than in the rest of the task (see section 2.4.2 for a full explanation).

Finally, Study 1 re-emphasised the difficulty in creating an ISL task suitable for engaging autistic children with more pronounced learning difficulties. It was suggested that passive ISL tasks (Jeste et al., 2015; Scott-Van Zeeland et al., 2010) and tasks more closely integrated into child-friendly games (McKinney et al., 2021) may be better suited to quantifying ISL in Study 1's target participants. Given the aforementioned successes of Study 1, it would seem sensible to apply the latter solution to the ISL task. Through a process of 'gamification' (Deterding et al., 2011; Sailer & Homner, 2020), the task could conceivably be developed to be make it more engaging for autistic participants. Game-

[31] In Study 1, the disruption block required fewer responses (and took less time to complete) than the learning-phase blocks. Fatigue-based RT deterioration may, therefore, have been reduced in the disruption block (relative to the longer learning-phase blocks), resulting in faster mean RTs.

like elements, such as a basic storyline/objective, stimulating graphics and more rewarding gameplay, could be added to the task. These elements, used alongside the task's existing probabilistic structure and simple response interface, may increase the task's ability to engage and sustain the attention of young autistic children.

With the above-mentioned modifications to the ISL task in place, Study 1 should ideally be re-run in its entirety, including the second phase of testing specified in its original longitudinal design (see section 2.1.2). Following Jones et al.'s (2018) finding that children with more severe autistic symptoms showed evidence of reduced ISL, there remains a sound rationale for investigating implicit learning in young, lower-functioning autistic children. Because Study 1 was not completed as intended, it is for future research to establish whether ISL follows different developmental trajectories in autistic and non-autistic populations. It is also important to discover how ISL ability predicts future language development and social functioning in young autistic children. A repetition of Study 1, using an appropriately modified version of the ISL task, could prove effective in answering these questions.

8.1.2. Implicit learning in the social domain (studies 2 and 3)

Following the premature termination of Study 1, research refocussed on implicit learning in the social domain, another area largely overlooked in previous research. Study 2 investigated how self-reported autistic traits related to implicit social learning. TD participants viewed 36 online presentations of a pro- and an anti-social character's dynamic facial cues. A gaze direction response task required participants to attend closely to the characters' eyes throughout this learning phase. The majority of participants remained unaware of the cues but, nevertheless, liked the pro-social character more than the anti-social character. In contrast to similar studies by Hudson et al. (2012) and Macinska (2019), Study 2 found no evidence that higher autistic traits were associated with reduced learning. Instead (and against initial predictions), likeability difference (LD) correlated positively with AQ-S.

Because participants viewed all 36 social cue presentations before rating the characters, Study 2 could not investigate implicit learning *efficiency* or how it might relate to dimensional autistic traits. Study 3 tested how 24 and 12 facial cue presentations affected learning. Contrary to predictions, the medium and short exposure conditions appeared not to foster sufficient implicit learning to influence participants' character likeability judgements. However, multilevel analyses of the combined data from studies 2 and 3 again indicated that AQ-S correlated positively with LD.

To the author's knowledge, these studies provided the first demonstration of a positive relationship between autistic traits and any form of social learning. Because even sub-clinical autistic traits are known to correlate negatively with social functioning and awareness (Sasson et al., 2013; Wainer et al., 2011), this positive correlation remains difficult to explain. A goal for future research is to replicate the positive AQ-S/LD correlation found in studies 2 and 3, and to investigate the mechanism behind it. Several potential explanations for this finding were proposed in section 6.4. An autism-related Bayesian 'learning rate' imbalance (Chrysaitis & Seriès, 2022) and/or a local processing advantage may be compatible with the positive correlation. Other autistic trait-related factors, such as the self-selection of favourable testing conditions, increased attention to the learning-phase stimuli and facilitation of implicit learning by the online/on-screen presentation of cues, may also have influenced study 2 and 3's findings. However, the studies did not collect data that could support or falsify these proposed mechanisms. As detailed in section 6.4.1, it is therefore recommended that these factors are investigated further (or at least controlled for) if these studies were to be repeated.

8.1.3. Attentional factors and implicit social learning (Study 4)

In studies 2 and 3, participants were required to attend to the characters' eyes. Gaze indifference and avoidance, which are associated with autistic traits, were therefore prevented from affecting social learning. Study 4 (again conducted online) removed this constraint, allowing participants to allocate their attention more freely. Under this condition, no significant correlation was found between autistic traits and LD. This finding supports suggestions that autism-related attentional factors (Chevallier et al., 2012; Hadjikhani et al., 2017; Tottenham et al., 2014) may moderate learning from facial cues.

After Study 4 had been conducted, Macinska and colleagues (2023) published an eye-tracking study that investigated participants' allocation of attention as they viewed stimuli comparable to those used in studies 2, 3 and 4. When participants viewed the 'facial cue' video clips without specific instructions, HFA adults spent significantly less time fixated on the characters' eyes (and more time fixated on the nose) than TD controls. However, when TD participants were placed into higher- and lower-autistic-trait groups (based on AQ score), there was no significant difference in eye fixation times between groups.

As was the case in Macinska's (2019) earlier study, anger (rather than disgust) was used as the negative emotion in the video clips. As such, threat detection may have influenced allocation of attention (see section 4.1.1). Nevertheless, given Macinska et al.'s (2023) latest findings, it would be interesting to re-run this series of studies with autistic participants. It might be predicted that the 'eye monitoring' requirement would affect autistic participants more than controls. Such a finding would further implicate attention as an important moderator of implicit social learning in ASD.

8.1.4. Implicit social learning and its influence on cognition (Study 5)

Study 5 (conducted in the laboratory) investigated the possibility that autistic individuals experience a disconnect between implicit learning and its subsequent influence on cognition. Following a facial cue learning phase, autistic and TD participants completed an affective priming task which used neutral-expression photographs of the pro- and anti-social characters as primes. No evidence of the predicted 'valence congruence' or 'negative priming' effects was found. Implicit learning appeared to exert little influence on priming task responses, perhaps suggesting that Study 5's novel priming paradigm lacked sensitivity. However, this conclusion is at odds with the significant priming effect that *was* detected in the ASD group. Against predictions, autistic participants took longer to respond to positive character-primed targets than to negative character-primed targets. The mechanism behind this effect remains unclear, though it could potentially relate to an autism-associated atypicality in the implicit processing of positively valenced stimuli (Wilbarger et al., 2009).

Unlike in Study 2, no significant differences in character likeability ratings were later detected in either set of participants, possibly indicating the vulnerability of implicit social representations to retroactive interference. This null finding did, however, mean that the 'positive character inhibition' effect was the only empirical indication that learning took place during Study 5. That this effect was detected only in the autistic participants again suggests that they do not share a fundamentally reduced ability to learn implicitly. Instead, it may be the influence of implicit learning on subsequent cognitive processes that is atypical in ASD.

8.2. Interpreting the findings

Unlike previous research by Hudson et al. (2012) and Macinska (2019), none of the studies in this thesis produced evidence that increased autistic traits (or ASD diagnoses) were associated with a reduced ability to learn social information implicitly. While all of the studies mentioned here used a similar learning phase, they also contained significant methodological differences. These differences should be considered when attempting to reconcile the various studies' mixed findings.

Studies by Hudson et al. (2012) and Macinska (2019) both utilised 'facial cue' learning phases and found evidence of reduced implicit social learning in high-autistic-trait participants (see section 4.1). Following Hudson et al.'s learning phase (during which participants' attention *was* constrained to the characters' eyes), the pro- and anti-social characters were employed in a speeded gaze-cueing paradigm. Low-AQ participants exhibited a reduced gaze-cueing effect for the anti-social character (consistent with accurate learning of the character's disposition), whereas the high-AQ participants responded similarly following both characters' cues (indicating impaired implicit learning). In Macinska's study, the learning phase was followed by a morph judgement task (a variation on which is described below). A perceptual bias aligned with the social cues (indicative of successful learning), was created in the low-AQ participants only. However, Macinska also found that explicit character likeability ratings (completed after the morph judgment task) suggested that both low- and high-AQ participants had developed a similar preference for the positive character. This second finding indicated no difference in implicit learning between the two groups. In this respect, Macinska's finding was similar to Study 4's. Even when participants could allocate their attention freely, neither study found a negative relationship between participants' autistic traits and the accuracy of their social judgements.[32]

[32] In Study 4, while the pro-social character was rated (on average) as more likeable than the anti-social character, the likeability difference between the two did not reach statistical significance.

Just as this thesis was being prepared for submission, Jellema et al. (2024) published a ‘hypothesis and theory’ article detailing results from preliminary experiments related to Macinska’s work. Just as in Macinska’s (2019) earlier study, Jellema et al.’s learning phase used anger as the negative emotion and did not require participants to attend to the characters’ eyes. This time, though, Jellema et al. included a second version of the learning phase that was identical in structure to the original but lacked any social components. Two shapes (a square and a circle) were used in place of the two characters. The dynamically transitioning colour of these shapes (light blue to dark blue) became the equivalent of the happy or angry facial expressions, while a vertically moving red dot replaced the change of gaze direction. Like the characters in the social learning phase, each shape was consistent in its presentation of cues. For example, just as one character in the social learning phase always smiled while looking toward the participant, one of the shapes (in the non-social version) always paired a light blue colour with the red dot positioned towards the top.

To assess implicit learning from these comparable sets of cues, TD participants completed morph judgement tasks. In the ‘social’ task, participants viewed a morphed composite image of the two learning-phase characters and were asked which character it most closely resembled. Each morphed image was a combination of the two characters sporting happy facial expressions *or* a combination of both characters sporting angry facial expressions. Of particular interest were participants’ judgements of morphs that contained exactly 50% of each character. If implicit social learning had taken place, participants were predicted to judge the smiling 50:50 morph as more similar to the pro-social character, while the angry 50:50 morph would be judged as more closely resembling the anti-social character. The ‘non-social’ morph judgement task was structured in the same way. Participants were asked to indicate which of the learning-phase shapes a morphed composite most closely resembled. However, in this version, participants could only have acquired implicit knowledge of the visual cue contingencies specific to each shape, as no emotional or deictic information had been presented.

Like many previous studies, Jellema et al. (2024) found no relationship between participants’ autistic traits and performance on the non-social implicit learning task. However, a significant negative correlation was found for the social task. Increased autistic traits were associated with a reduction in the perceptual bias created by the social learning phase.[33] This combination of results again suggests that fundamental implicit learning mechanisms may remain intact in high-autistic-trait individuals. Instead, other factors that relate more specifically to the social domain may be atypical in autism.

8.2.1. Implicit social learning conclusions

As detailed above, several studies (included those presented in this thesis) have now investigated implicit social learning using a 'facial cue' learning phase. This section attempts to integrate their findings and draw conclusions about implicit learning and its relationship to autistic traits. These conclusions represent tentative interpretations of the limited data available.

Intact implicit learning ability: There is mounting evidence that the fundamental ability to learn implicitly remains intact in autistic and high-autistic-trait individuals. Meta-analyses found that autistic and TD participants performed similarly on a wide range of non-social implicit learning measures (Foti et al., 2015; Obeid et al., 2016). Even within the social domain, several studies have now shown that implicit learning is unaffected by, or in some cases correlated positively with, autistic traits. The studies that assessed implicit social learning using character likeability judgements were consistent in this finding. In studies 2 and 3, when participants' attention was constrained to the characters' eyes, autistic traits were associated with more 'socially accurate' ratings. Neither Macinska (2019, Experiment 1) nor Study 4 required participants to attend to the characters' eyes. Even so, both studies found that high- and low-autistic-trait participants did not differ significantly in the accuracy of their social judgements. Combined with evidence from Jellema et al. (2024), which again demonstrated intact non-social implicit learning in autistic participants (see previous section), the fundamental capacity for implicit learning seems not to diminish in the presence of increased autistic traits.

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[33] 37 of the 89 participants recruited to Jellema et al.'s (2024) preliminary studies completed both the social and non-social tasks, potentially undermining the implicit/non-conscious nature of paradigm. Jellema et al. reported that further testing was planned though, including studies to determine whether the disparity between social and non-social task performance could be even greater when autistic individuals are tested.

Social attention moderates implicit learning: There are, however, several factors that could influence implicit *social* learning, even if the capacity for implicit learning is preserved in autism. Social attention is one such factor. Autistic traits are associated with a reduction in attention to others' eyes, a key source of social information in all of the studies discussed here. Macinska and colleagues (2023) showed that, when autistic participants viewed the 'facial cue' video clips without specific instructions, they spent significantly less time than controls looking at the characters' eyes. In studies 2 and 3, when participants were required to attend to the characters' eyes, AQ-S scores correlated positively with LD. When attention was not constrained to the eyes (Study 4), no significant correlation was found. Attentional differences, related to autistic traits, may therefore translate into observable differences in implicit social learning.

No evidence that social cognitive deficits hinder implicit learning: This thesis produced no evidence that social cognitive deficits associated with ASD hindered implicit learning. It was suggested in section 3.2 that disrupted processing of affect and/or reduced automatic mentalising had the potential to harm social learning, even in the absence of an implicit learning deficit. With participants' attention constrained to the characters' eyes, both proposed cognitive deficits were predicted to contribute to a negative AQ-S/LD correlation. However, the positive AQ-S/LD relationship found when attentional factors were controlled for (studies 2 and 3) provided evidence counter to this prediction. Social cognitive factors are discussed further in section 8.3.3.

Atypical influence of learning on subsequent implicit cognitive processes: Implicit learning capacity appears to remain intact in autism, but atypical allocation of attention may limit social learning opportunities. As such, one might expect implicit learning to be detected (regardless of autistic traits) whenever participants were required to attend to the characters' eyes. However, looking at just those studies in which attention *was* constrained to the eyes, the outcome appeared to be contingent on the way implicit learning was assessed. Subsequent tasks that involved fast, automatic processing tended to detect autism-related atypicalities, whereas learning assessments that allowed slower explicit processing did not.

In studies 2 and 3, autistic traits related to more accurate (slow, explicit) likeability judgements. Hudson et al. (2012), however, used a gaze-cueing task to quantify learning. This task, which required fast, automatic, implicit processing, detected learning in the low-autistic-trait participants only. Assuming, for the moment, that implicit learning remains intact in autism, these results could reflect an atypicality in the way implicitly learned social information affects other automatic cognitive responses. Study 5's results could also be interpreted in these terms. Only the autistic participants showed evidence of learning, but this learning seemingly affected (fast, implicit) valence decisions in an atypical way, creating the unpredicted 'positive character inhibition' effect. This small pool of studies provides insufficient evidence to conclude with any certainty the presence of an implicit processing atypicality/disconnect. However, it is recommended that future researchers investigate the possibility that implicitly learned social information affects automatic cognitive processes differently in TD and autistic individuals.

8.3. Methodological limitations and recommendations for future research

Various methodological limitations, related to studies 1-5, have been discussed throughout this thesis and will not be repeated here. Instead, this section identifies broader limitations in this research area that prompt recommendations for future research.

8.3.1. Autistic trait assessment

All of the 'implicit social learning' studies discussed here used either the Autism-Spectrum Quotient (AQ, Baron-Cohen et al., 2001b) or the related AQ-S (Hoekstra et al., 2011) to quantify participants' autistic traits. The AQ in particular (which is described in section 3.1) has been used extensively in autism research. The AQ-S, which is highly correlated with the AQ, was selected for use in studies 2-5 because of its shorter administration time. However, since the development of these measures, knowledge of autistic symptomatology has advanced significantly. For example, the presentation of autism in females is becoming better understood (Hull, L. et al., 2020; Lundström et al., 2019; Napolitano et al., 2022; Whitlock et al., 2020) as are sensory disturbances (Ben-Sasson et al., 2019; Hazen et al., 2014; Robertson, C. E. & Baron-Cohen, 2017b), which are not assessed by either the AQ or AQ-S. It could therefore be argued that these measures provide an outdated assessment of the traits associated with autism.

Measures that reflect a more contemporary understanding of autism have been developed though. The Comprehensive Autistic Trait Inventory (CATI, English et al., 2021), for example, contains 'new' subscales that assess 'social camouflage' and 'sensory sensitivity' alongside more traditional 'social interaction', 'communication', 'repetitive behaviour' and 'cognitive rigidity' subscales. The CATI has proven sensitive to subtle sex-related differences in autistic trait presentation (English et al., 2021, 2024) and has, so far, retained its psychometric properties when used in different languages and cultures (Kordbagheri et al., 2024; Meng & Xuan, 2023). It is recommended that contemporary measures, such as the CATI, are used in future research. Such measures would allow researchers to test implicit learning (and other cognitive abilities) against conceptualisations of dimensional autistic traits that are better-informed by more recent research.

8.3.2. Social learning phase development

Research investigating implicit social learning is in its infancy. Just a handful of studies have so far been conducted, most using variations on the same 'facial cue' learning phase. While this learning phase has generally proven effective, aspects of it could perhaps be improved. Depending on how implicit learning is later assessed, it is important that the intended valances become attached to the pro- and anti-social characters. However, evidence from this thesis suggests that this step may not reliably take place. In studies 2-4, LD was used to quantify learning. In these studies, a useful measure of learning (LD) was derived whether participants liked both characters, disliked both characters or liked one character but disliked the other. Essentially, learning could be identified by the existence of a significant valence difference (between characters), regardless of what those valences were.

However, Study 5 (which used an affective priming task to quantify learning) *required* the pro-social character to acquire a positive valence and the anti-social character to acquire a negative valance. If, for example, a participant had developed a positive view of both characters, the priming task would essentially contain no negative primes (for that participant). This particular learning outcome could potentially render an intended ‘negative prime/positive target’ trial as congruent, rather than incongruent. If a participant had instead *disliked* both characters, a ‘positive prime/positive target’ trial could be viewed as incongruent for that participant. Such unanticipated patterns of learning could also have added unwanted response variability to Hudson et al.’s (2012) gaze-cuing task and Macinska’s (2019) and Jellema et al.’s (2024) morph judgement tasks.

These ‘unintended’ learning patterns are not just a possibility though. In Study 2, participants’ social evaluations of the characters varied greatly.[34] The pro-social character received ratings ranging from 15 (strongly disliked) to 88.75 (strongly liked). Similarly, the anti-social character received ratings from 16.5 to 92.5. Of the 26 participants with a positive LD (indicative of accurate social learning), 11 rated the anti-social/negative character as likeable/positive (as indicated by likeability ratings greater than 50).

One strategy to account for these inconsistencies would be to 'calibrate’ responses to priming, gaze-cuing and morph judgement tasks using measures of individual participants’ learning. For example, as described above, a participant who liked both characters could be considered to view only positive primes in the priming task. This tactic would present its own difficulties though. Firstly, one would have to assume that explicit likeability ratings (or other quick assessments of learning phase outcomes) better reflect implicit social learning than the measures they are being used to calibrate. Further research would be required to verify this assumption. Secondly, the timing of any explicit learning assessment would be problematic. Ratings taken immediately after the learning phase are likely to be the most accurate. However, they may also draw participants’ attention to the true purpose of the study, eliminating the implicit nature of the task that follows. Explicit learning measures taken *after* an intervening task may be subject to retroactive interference though (see section 7.4.1), rendering them unreliable as calibration tools. Because of these difficulties, it is recommended that the learning phase cues continue to be refined. By altering the number of presentations, use of different (perhaps more aesthetically neutral) actors, timing changes within the

[34] Study 2 constrained participants’ attention to the characters’ eyes, presented the maximum number of social cues (36) and assessed character likeability immediately after the learning phase. This study therefore provides the clearest available indication of participants’ attitudes toward the characters following the learning phase social cues.

videos (for example, faster or slower emotion/gaze direction transitions) or some other manipulation, it may be possible to create learning-phase videos that more reliably foster the intended social learning outcomes.

8.3.3. Data analyses and extrapolation of findings

As discussed above, the 'facial cue' learning phase tended to produce small effect sizes and highly varied 'likeability' outcomes. It is therefore important that suitably sensitive analytical methods are deployed to investigate this type of social learning. Following exposure to a similar learning phase, Macinska (2019) and Macinska et al. (2023) placed TD participants into higher- and lower-autistic-trait groups (based on AQ score median split). These studies found no significant differences in likeability ratings and eye fixation times between groups. When Study 2 employed the same 'median split' method, it too found no main effect of 'group' on likeability difference. However, by moving from a 'group differences' approach to correlational analyses, a significant positive relationship between AQ-S and LD was revealed. Future researchers are therefore advised to proceed with caution when dividing participants into groups on the basis of a continuous autistic trait measure. Study 2 indicated clearly that this practice may obscure an otherwise detectable relationship between dimensional autistic traits and implicit social learning.

Researchers should also be aware that findings from TD participants do not always extrapolate well to those with autism. As mentioned, Macinska et al. (2023) found no significant difference in eye fixation times between high- and low-autistic trait TD participants. However, the same study (using the same methods) showed that autistic adults spent significantly less time looking at the learning-phase characters' eyes than did TD controls. As established in Section 3.1, many studies have produced useful insights after investigating TD participants' dimensional autistic traits and how they relate to implicit learning and other abilities. However, Macinska et al. (2023) showed that autism-related attentional differences can be subtle enough that they are only detected in autistic participants. The current iteration of the facial cue learning phase may produce autistic trait-related effects small enough that they are difficult to detect in TD participants. Depending on the method of assessment, research with diagnosed autistic participants may be the more effective way of investigating subtle social learning and attentional differences associated with the condition.

8.3.4. Measurement of additional variables

In section 3.2, evidence was presented that disruptions to emotion processing (alexithymia) and/or reduced implicit mentalising could potentially undermine implicit learning in the social domain. In studies 2-5, all non-excluded participants successfully identified the emotions displayed within the learning phase. Furthermore, the positive AQ-S/LD correlation found in studies 2 and 3 appeared incompatible with reduced implicit ToM processing. However, neither alexithymia nor implicit mentalising have been assessed directly in any implicit social learning study. Studies have therefore been unable to control for their effects when analysing results.

Emotion processing: Alexithymia is commonly assessed using self-report measures, with the Toronto Alexithymia Scale (Bagby et al., 1994) being, historically, the most popular choice. However, scores on this particular scale might reflect current levels of psychological distress rather than alexithymia itself (Leising et al., 2009). The Bermond–Vorst Alexithymia Questionnaire (Vorst & Bermond, 2001) and the Perth Alexithymia Questionnaire (Preece et al., 2018) are considered more valid and reliable measures of alexithymic traits (Greene, D. et al., 2020; Preece et al., 2020; Zech et al., 1999) and might be better choices for use in future research.

Implicit ToM processing: Individual differences in implicit mentalising are more difficult to quantify. As described in section 3.2.3, anticipatory looking during false-belief scenarios is thought to index automatic ToM processing. The results from such studies are inconsistent though, calling into question the very existence of a separate implicit ToM system (Kulke et al., 2018a, 2018b, 2019). Nevertheless, it would be interesting to compare implicit social learning in participants who do engage in false-belief-congruent anticipatory looking and those who do not. A significant difference in learning between these groups could implicate implicit mentalising as another factor that moderates learning from undetected social cues.

Local processing bias: A final variable that might be of interest to implicit learning researchers is local/global processing bias. It was suggested that the positive AQ-S/LD correlation in studies 2 and 3 (in which attention was constrained to the eyes) was potentially consistent with the autism-related advantage for processing small details and disembedding local figures. Disembedding the eyes within learning-phase video stimuli could conceivably have facilitated implicit social learning from the (mostly eye-based) cues (see section 6.4.1).

To test this proposal, it is recommended that participants' cognitive preference for local/global processing is assessed. As described previously, local visual processing is often measured using the Embedded Figures Test (Witkin, 1971). Global visual processing could be assessed using the Fragmented Pictures Test (Kessler et al., 1993). In this task participants are required to identify the object in an image as early as possible as fragments of the image are sequentially revealed. Faster identification of the object reflects an increased ability to combine visual fragments into a meaningful whole. If Study 2 were to be repeated, it would be interesting to see whether increased local processing ability (or reduced global processing ability) accounted for significant variation in implicit learning, given the screen-based, eye-centric paradigm employed.

8.3.5. Explicit versus implicit processing

Moving away from implicit social learning, the final recommendation relates to a study planned for this thesis' original (pre-COVID) programme of research. Section 1.5.2 presented evidence that people with autism may use explicit learning strategies in situations that would typically elicit implicit processing. These situations may include serial reaction time (SRT) tasks developed to assess implicit learning. While most SRT studies detected similar sequence-related RT improvements in autistic and control groups, the cognitive mechanisms underlying those performances may have differed. Zwart et al. (2018) further suggested that overreliance on explicit learning strategies may harm social learning in autistic individuals, even if implicit learning remained intact. Evidence for an autism-related explicit learning bias came mostly from brain-scanning studies. Though it has yet to be conducted, a study planned for inclusion in this thesis could have provided the first behavioural demonstration of such a processing preference.

Autistic and TD participants would have completed two SRT tasks, using similar visual stimuli and response keys to Iao and colleagues (2021). Unbeknownst to participants, stimuli presentation in both tasks would have been governed by a Markov chain sequence similar to that used in Study 1 (see section 2.2.4). Task 1 would have been described to participants as a simple ‘baseline RT test’. The absence of external motivation to process the sequence explicitly would have made Task 1 the ‘implicit learning condition’. Before Task 2 though, participants would have been informed of a hidden sequence and instructed to discover it over the course of the task. In reality, Task 2 would have repeated the sequence from Task 1, but alternative visual stimuli and keyboard response keys would have disguised any similarity. The additional cognitive load of ‘trying to learn’, when the task is sufficiently complex, is known to harm learning (Finn et al., 2014; Fletcher et al., 2005; Howard & Howard, 2001). Because the sequence in Task 2 would have featured no periodically repeating pattern, it would have been almost impossible to learn explicitly. TD participants’ learning in Task 2 (as quantified by RT improvements as the task progressed) was therefore expected to be significantly poorer than in Task 1. However, if the autistic participants had ‘self-imposed’ an explicit learning strategy during Task 1 (i.e., they had attempted explicit learning in both tasks), similar learning outcomes in tasks 1 and 2 would be predicted. A study based on these principles should therefore produce behavioural evidence of an autism-related explicit learning strategy preference, if one exists.

8.4. Summary and concluding remarks

Because Study 1 was cut short, it was not able to determine whether ISL is deficient in younger, lower-functioning autistic children. Study 1’s novel touchscreen task, which proved inaccessible for many autistic children, requires refinement. However, its learning sequences (based on transitional probabilities) increased the ecological validity of the task and successfully fostered learning in children as young as 4 years old. Study 1 also introduced the recording of ‘lift’ reaction times, which could reduce the influence of autism-related sensorimotor disturbances in future research.

Studies 2 and 3 produced arguably the most significant finding of this thesis. Under certain conditions, increased dimensional autistic traits were associated with *superior* implicit social learning from facial cues. This finding constitutes the first demonstration of a positive relationship between autistic traits and any form of social learning. Several factors that possibly contributed to this effect were identified for future investigation. ‘Attention’ was one such factor. Study 4 suggested that an autistic trait-related reduction in attention to others’ eyes may moderate implicit learning from facial cues.

A more tentative inference from Study 5 was that implicit learning may influence subsequent cognition atypically in autistic individuals. Following the learning phase, autistic participants (against predictions) took longest to respond to positive character-primed targets. Combined with the findings of Hudson et al. (2012), who used a gaze-cueing task to quantify learning, evidence potentially indicates that implicit learning affects rapid, automatic cognitive processes differently in autistic and TD participants. The absence of predicted priming effects in Study 5 might also have reflected a limitation of the learning phase. The ‘facial cue’ videos did not reliably produce the intended social learning outcomes (in Study 2) and may require modification ahead of future experiments.

While studies 1-5 were able to provide few definitive conclusions, useful insights were produced that could guide future research. It is hoped that replication and refinement of the techniques developed for this thesis lead to a clearer understanding of the relationship between implicit learning and autistic symptomatology. As identified in section 1.5, several popular interventions teach language and social skills to autistic children without explicit instruction, instead relying on children’s ability to learn implicitly. A better understanding of the factors that influence non-conscious learning might therefore aid the development of autism-related therapies. Evidence from this thesis generally supports suggestions that the fundamental capacity for implicit learning remains intact in those with elevated autistic traits. It is therefore recommended that other factors that could limit learning, and the influence of implicit learning on subsequent cognition, become the focus of future studies.

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Appendix

Table A1

Affective priming task target words (Study 5)

Positive words	Valence	Frequency	Negative words	Valence	Frequency
lovable	8.26	1.78	**unhappy**	1.84	16.53
joyful	8.21	1.49	**toxic**	2.35	4.90
honest	8.16	72.33	**jealous**	2.38	38.27
cheerful	8	3.73	**frightened**	2.45	23.25
faithful	7.95	9.12	**hostile**	2.35	8.94
talented	7.95	11.39	**repulsive**	1.95	2.02
friendly	7.84	26.04	**racist**	2.05	4.82
healthy	7.76	24.75	**greedy**	2.1	6.63
successful	7.76	20.33	**terrible**	2.1	94.02
smart	7.73	96.25	**sad**	2.1	63.37
amazing	7.72	81.71	**disgusting**	2.27	26.61
romantic	7.61	35.18	**revolting**	2.47	1.92
gorgeous	7.57	24.06	**hopeless**	2.2	8.94
confident	7.56	10.65	**insecure**	2.3	4.06
sunshine	8.14	11.84	**disease**	1.68	26.18
lover	8.05	26.63	**virus**	1.71	18.90
prize	8	22.39	**bomb**	2.47	53.65
award	7.86	12.88	**cancer**	1.9	22.33
waterfall	7.79	1.86	**parasite**	1.9	2.47
wildlife	7.75	1.92	**prison**	1.94	66.04
starlight	7.68	1.59	**vomit**	1.98	5.33
tree	7.59	65.00	**pain**	2	97.94
chocolate	7.63	29.39	**pollution**	2	1.90
oasis	8	1.92	**funeral**	2.07	33.20
song	7.59	93.69	**scum**	2.12	9.90
savings	7.67	7.53	**poison**	2.16	24.55
kitten	7.58	4.73	**maggot**	2	1.59
hug	8.23	19.33	**debt**	1.95	14.22
panda	7.55	2.12	**headache**	2.22	14.10
savings	7.67	7.53	**cockroach**	2.46	3.41

Note. Target words and valances from Warriner et al. (2013). Word frequencies (frequency per million words) from the SUBTLEX-US corpus (Brysbaert & New, 2009). Positive and negative target words differed significantly on valence but not on frequency, word length or number of syllables (see section 7.2.3).