

UNIVERSITY OF IOANNINA

SCHOOL OF SOCIAL SCIENCES

DEPARTMENT OF PSYCHOLOGY

Exploring different sources of variation in implicit learning in young people with and without autism

PhD thesis

Adamantia Ziva

Ioannina 2026

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In loving memory of my mother

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Abstract

Much of what people learn through everyday experience is acquired without deliberate attempts to identify or memorise the patterns involved. This form of learning, known as implicit learning, plays an important role across both typical and atypical development, yet research on implicit learning in autism has produced mixed findings, with some studies reporting preserved and others reduced or enhanced learning in people with autism compared with typically developing (TD) participants. This thesis examines whether characteristics related to the cognitive profile of autism may contribute to this variation, using Artificial Grammar Learning (AGL) paradigms combined with sensitive measures that distinguish implicit from explicit knowledge.

The Introduction, in Chapter 1, focuses on theoretical and methodological issues related to the study of implicit learning as well as on a combination of factors that might explain the inconsistency of the results of prior research and justify potential differences in the implicit of autistic and TD individuals. Chapter 2 presents Study 1, which examined implicit learning in autistic and TD children and adolescents, with the autistic group covering a wide range of intellectual ability and symptom severity. Both groups demonstrated implicit learning, although for the autistic group implicit learning performance was weaker compared with that of their TD peers. Implicit learning was not reliably related to IQ or autism symptom severity. Exploratory analyses using a separate Navon task suggested a potential relationship between processing tendencies and implicit learning. These findings provided the basis for a more direct examination of this possible relationship in Study 2, which is presented in Chapter 3.

Study 2 used a GLOCAL AGL paradigm to examine more directly whether processing tendencies are related to implicit learning performance. Global–local processing is especially relevant to autism, as differences between autistic and non-autistic individuals in the processing of global vs local information have been proposed as one aspect of the cognitive profile associated with the condition, including a possible reduced tendency among autistic individuals to process information globally. Both groups gained implicit knowledge at both global (more holistic) and local (more detailed) levels, but implicit learning of global structures was reduced in participants with autism compared with TD participants, whereas learning of local structures did not differ substantially between groups. The general pattern

of findings suggested that processing tendencies, and possibly the different priority given to global vs local information by the two different groups of participants may contribute to differences in implicit learning performance between autistic young people and their TD counterparts.

Chapter 4 describes Study 3, which investigated whether the implicit learning of social vs neutral information differed between autistic and TD young individuals. The use of the specific comparison of stimuli is of major interest given the difficulties autistic people face with social interaction and communication. Autistic and TD participants learned regularities involving social stimuli (faces) and non-social stimuli (colours) within the same AGL paradigm. Participants with autism demonstrated implicit learning from both types of information, but the overall pattern of findings showed greater difficulty learning from social than from non-social stimuli, relative to their TD peers. This pattern suggests that the social relevance of information may be an important source of variation in implicit learning performance in autism.

Overall, the findings support a view of implicit learning in autism as relatively preserved but context dependent. Across the three studies, participants with autism showed the ability to gain knowledge implicitly, but the extent to which they benefited from particular sources of information varied. This provides a possible explanation for some of the mixed findings in the literature and highlights the importance of considering the conditions under which implicit learning occurs in autism. Chapter 5 discusses the implications of these findings, some potential applications and limitations regarding their generalisability to different contexts

Περίληψη

Μεγάλο μέρος της γνώσης που αποκτούν οι άνθρωποι μέσα από την καθημερινή τους εμπειρία αποκτάται χωρίς σκόπιμη προσπάθεια αναγνώρισης ή απομνημόνευσης των εμπλεκόμενων μοτίβων. Αυτή η μορφή μάθησης, γνωστή ως άδηλη μάθηση, διαδραματίζει σημαντικό ρόλο τόσο στην τυπική όσο και στη μη τυπική ανάπτυξη. Ωστόσο, η έρευνα σχετικά με την άδηλη μάθηση στον αυτισμό έχει οδηγήσει σε αντικρουόμενα ευρήματα, με ορισμένες μελέτες να αναφέρουν διατήρηση της άδηλης μάθησης στα άτομα με αυτισμό, ενώ άλλες μειωμένη ή ενισχυμένη μάθηση στα άτομα αυτά σύγκριση με τυπικά αναπτυσσόμενους (ΤΑ) συμμετέχοντες. Η παρούσα διατριβή εξετάζει κατά πόσο ορισμένα χαρακτηριστικά που σχετίζονται με το γνωστικό προφίλ του αυτισμού μπορεί να συμβάλλουν σε αυτή τη διαφοροποίηση, χρησιμοποιώντας παραδείγματα Μάθησης Τεχνητής Γραμματικής (ΜΤΓ) σε συνδυασμό με ευαίσθητες μετρήσεις που διακρίνουν την άδηλη από τη έκδηλη γνώση.

Η Εισαγωγή στο Κεφάλαιο 1 επικεντρώνεται σε θεωρητικά και μεθοδολογικά ζητήματα που σχετίζονται με τη μελέτη της άδηλης μάθησης, καθώς και σε έναν συνδυασμό παραγόντων που θα μπορούσαν να εξηγήσουν την ασυνέπεια των αποτελεσμάτων προηγούμενων ερευνών και να αναζητήσουν πιθανές αιτίες για τις διαφορές στην άδηλη μάθηση μεταξύ ατόμων με αυτισμό και ατόμων ΤΑ. Το Κεφάλαιο 2 παρουσιάζει τη Μελέτη 1, η οποία εξέτασε την άδηλη μάθηση σε παιδιά και εφήβους με αυτισμό και σε παιδιά και εφήβους τυπικής ανάπτυξης, με την ομάδα των αυτιστικών συμμετεχόντων να καλύπτει ένα ευρύ φάσμα νοητικών ικανοτήτων και σοβαρότητας των συμπτωμάτων αυτισμού. Και οι δύο ομάδες παρουσίασαν άδηλη μάθηση, αν και η επίδοση στην άδηλη μάθηση της ομάδας με αυτισμό ήταν χαμηλότερη σε σύγκριση με εκείνη των ΤΑ συνομηλίκων τους. Η άδηλη μάθηση δεν σχετιζόταν αξιόπιστα με τον δείκτη νοημοσύνης ή τη σοβαρότητα των συμπτωμάτων. Διερευνητικές αναλύσεις με τη χρήση ενός ξεχωριστού έργου τύπου Navon υπέδειξαν μια πιθανή σχέση μεταξύ των τάσεων επεξεργασίας και της άδηλης μάθησης. Τα ευρήματα αυτά αποτέλεσαν τη βάση για μια πιο άμεση εξέταση αυτής της πιθανής σχέσης στη Μελέτη 2, η οποία παρουσιάζεται στο Κεφάλαιο 3.

Η Μελέτη 2 χρησιμοποίησε ένα παράδειγμα ΜΤΓ που συνδυάζει την ολιστική και την εστιασμένη επεξεργασία της πληροφορίας, προκειμένου να εξετάσει πιο άμεσα κατά πόσο οι τάσεις επεξεργασίας σχετίζονται με την επίδοση στην άδηλη μάθηση. Η ολιστική vs εστιασμένη επεξεργασία έχει ιδιαίτερη σχέση με τον αυτισμό, καθώς οι διαφορές μεταξύ αυτιστικών και μη αυτιστικών ατόμων ως προς την επεξεργασία πληροφοριών σε ολιστικό

vs εστιασμένο επίπεδο έχουν αναδειχθεί ως ένα από τα στοιχεία του γνωστικού προφίλ που συνδέονται με τον αυτισμό, συμπεριλαμβανομένης μιας πιθανής μειωμένης τάσης των αυτιστικών ατόμων να επεξεργάζονται τις πληροφορίες σε ολιστικό επίπεδο. Και οι δύο ομάδες απέκτησαν άδηλη γνώση τόσο στο ολιστικό όσο και στο εστιασμένο επίπεδο, αλλά η άδηλη μάθηση των κανονικοτήτων σε ολιστικό επίπεδο ήταν μειωμένη στους συμμετέχοντες με αυτισμό σε σύγκριση με τους συμμετέχοντες ΤΑ, ενώ η μάθηση των κανονικοτήτων σε εστιασμένο επίπεδο δεν διέφερε ουσιαστικά μεταξύ των ομάδων. Η συνολική εικόνα των ευρημάτων έδειξε ότι οι τάσεις επεξεργασίας και, πιθανώς, η διαφορετική προτεραιότητα που δίνεται στην ολιστική έναντι της εστιασμένης επεξεργασίας των πληροφοριών μπορεί να συμβάλλουν στην ύπαρξη διαφορών στην επίδοση στην άδηλη μάθηση μεταξύ νεαρών ατόμων με αυτισμό και της αντίστοιχης ομάδας ατόμων τυπικής ανάπτυξης.

Το Κεφάλαιο 4 παρουσιάζει τη Μελέτη 3, η οποία διερεύνησε κατά πόσο η άδηλη μάθηση κοινωνικών έναντι μη κοινωνικών πληροφοριών διέφερε μεταξύ αυτιστικών και ΤΑ νεαρών ατόμων. Η χρήση της συγκεκριμένης σύγκρισης ερεθισμάτων παρουσιάζει ιδιαίτερο ενδιαφέρον, δεδομένων των δυσκολιών που αντιμετωπίζουν τα άτομα με αυτισμό στην κοινωνική αλληλεπίδραση και επικοινωνία. Και οι δύο ομάδες έμαθαν τις κανονικότητες που αφορούσαν σε κοινωνικά ερεθίσματα (πρόσωπα) και μη κοινωνικά ερεθίσματα (χρώματα) στο πλαίσιο του ίδιου παραδείγματος ΜΤΓ. Οι συμμετέχοντες με αυτισμό απέκτησαν άδηλη μάθηση και από τους δύο τύπους ερεθισμάτων, αλλά η συνολική εικόνα των ευρημάτων έδειξε μεγαλύτερη δυσκολία στη μάθηση από τα κοινωνικά σε σχέση με τα μη κοινωνικά ερεθίσματα, σε σύγκριση με τους ΤΑ συνομηλίκους τους. Τα ευρήματα αυτά δείχνουν ότι η κοινωνική συνάφεια της πληροφορίας μπορεί να αποτελεί σημαντικό παράγοντα διαφοροποίησης της επίδοσης άδηλης μάθησης στον αυτισμό.

Συνολικά, τα ευρήματα υποστηρίζουν την άποψη ότι η ικανότητα άδηλης μάθησης στον αυτισμό διατηρείται αλλά εξαρτάται από το πλαίσιο. Και στις τρεις μελέτες, οι συμμετέχοντες με αυτισμό έδειξαν την ικανότητα να αποκτούν γνώση άδηλα, αλλά ο βαθμός στον οποίο επωφελούνταν από συγκεκριμένες πηγές πληροφορίας διέφερε. Αυτό παρέχει μια πιθανή εξήγηση για ορισμένα από τα αντικρουόμενα ευρήματα της βιβλιογραφίας και αναδεικνύει τη σημασία του να λαμβάνονται υπόψη οι συνθήκες υπό τις οποίες συντελείται η άδηλη μάθηση στον αυτισμό. Το Κεφάλαιο 5 συζητά τη σημασία αυτών των ευρημάτων, ορισμένες πιθανές εφαρμογές και τους περιορισμούς τους ως προς τη δυνατότητα γενίκευσής τους σε διαφορετικά πλαίσια.

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Preface

Everyday life is full of patterns, regularities, and relationships that we gradually come to recognize and use without necessarily being aware of when or how we learned them. This raised a particularly interesting question in the context of autism, where differences in the way information is processed have often been discussed, but where research on implicit learning has produced findings that are far from consistent.

What began as an interest in whether implicit learning is preserved in autism gradually developed into a broader question about what might shape how autistic individuals acquire and use implicitly learned information. Therefore, across the three studies, the focus moved from whether autistic young people can learn implicitly, to how the level at which information is processed and the type of information being learned may influence implicit learning.

The studies presented here represent different stages of that process. Each raised new questions that informed the next, gradually leading to a more nuanced understanding of implicit learning in autism and of the conditions that may affect how learning takes place. The thesis is therefore not only a collection of three studies, but also the development of a research question that became more specific as the work progressed.

Chapter 1

General Introduction

Implicit learning in human cognition

Learning is typically considered as a process through which individuals gain new knowledge, skills, or behaviours as a result of experience, practice, or instruction. Although this process is often associated with conscious effort, a notable amount of learning may occur without people having an intention to learn. By being in an ongoing engagement with their environment, individuals can detect patterns and relationships in the information they encounter, gradually developing an understanding of how things are related and gaining knowledge of these patterns, even when they are not actively searching for them. This type of learning, usually termed as implicit learning, is considered an important component of human cognition and has been investigated across a wide range of domains, including language, motor abilities, perceptual processing and social cognition (e.g., Conway & Pisoni, 2008; Ivanchei et al., 2019; Kaufman et al., 2010; Reber, 1993; Van der Kamp et al., 2015) and across different populations including typically developing people of varying ages (e.g., Lukács & Kemény, 2015; Verneau et al., 2014), individuals with learning difficulties (e.g., Atwell et al., 2003; Merrill et al., 2014), or individuals with neurological or neurodevelopmental disorders (e.g., Barnes et al., 2010; Inácio et al., 2018).

One of the first experimental demonstrations of implicit learning was provided by Reber (1967) using the Artificial Grammar Learning (AGL) paradigm. In his original paradigm, participants first saw a set of letter strings which followed hidden rules. They were simply asked to memorize the exemplars without being aware that the strings were constructed following a set of rules. In a subsequent test condition, individuals saw new strings and were asked to decide whether each string followed the same rules. Although participants had not received explicit instruction concerning the grammatical rules, they were able to correctly classify the novel strings better than would be expected by chance. Moreover, they were generally unable to explain the rules they had learned, suggesting that people can learn complex patterns from experience without intentionally trying to discover or understand them.

The AGL paradigm became a prominent method for studying implicit learning (e.g., Pothos, 2007; Ziori & Pothos, 2015), and has since been adapted extensively, with researchers varying the complexity of the artificial grammars, the stimulus type, the duration of

exposure, and the procedures used to assess participants' knowledge.

Other major paradigms for investigating implicit learning

Although the AGL paradigm is one of the most well-established and frequently used methodological tools for the study of implicit learning, several other tasks have been developed to explore this form of learning across different cognitive areas. Two other well-known examples, the Serial Reaction Time (SRT) and the Contextual Cueing (CC) tasks, have been widely adopted. The SRT task (Nissen & Bullemer, 1987) is commonly used for the study of implicit sequence learning. Unlike AGL, which examines abstract structural regularities, SRT assesses learning of temporal regularities in visuomotor response sequences. Participants are usually asked to respond to stimuli appearing at different screen locations which follow a repeating sequence. Faster responses across repeated trials, followed by slower responses when the sequence is replaced by random trials, provide evidence of sequence learning. When participants cannot consciously identify the sequence, this indicates that at least part of the acquired knowledge is implicit. The CC task, established by Chun and Jiang (1998), has also been used to examine implicit learning in visual-search environments. Participants are asked to locate a target stimulus among distractors, with some spatial arrangements being repeatedly presented and others being completely new. Faster target detection in repeated configurations indicates that participants have learned the relationships between the visual context and the target location. Importantly, learning can emerge without conscious recognition of the repeated configurations, suggesting that such associations can be acquired implicitly (though see Kroell et al., 2019 for a discussion of contradicting evidence).

Other paradigms have extended the study of implicit learning to a wide range of cognitive domains. Probabilistic category learning tasks examine how people gradually acquire probabilistic relationships between cues and outcomes through feedback (Gluck & Bower, 1988), while prototype category learning tasks investigate whether individuals can learn the common features of a category through presentation of several examples, even when they are not instructed to identify the defining features (Posner & Keele, 1968). In addition, Dynamic Systems Control tasks investigate how individuals learn to control complex systems through repeated interaction (Berry & Broadbent, 1988), whereas statistical learning paradigms examine the ability to detect patterns in continuous information, particularly in language and speech (e.g., Aslin & Newport, 2012; Saffran et al., 1996, 1999). Together,

these paradigms demonstrate that implicit learning can support the learning of different types of patterns across perceptual, cognitive, motor, and language domains.

Implicit learning, conscious awareness, and the assessment of acquired knowledge

Although research has consistently shown that people can learn regularities without intentionally trying to do so, the nature of implicit learning has remained the subject of longstanding theoretical and methodological debate. Since Reber's (1967) foundational work on AGL, researchers have sought to determine whether implicitly acquired knowledge can influence behaviour independently of conscious awareness. Rather than functioning as separate, isolated processes, implicit and explicit forms of learning appear to coexist and influence learning outcomes across most learning conditions (e.g., Dienes & Scott, 2005; Sun et al., 2005, 2007; Ziori & Dienes, 2012, Ziori & Dienes, 2015). Thus, learning does not always result in knowledge that can be simply classified as implicit or explicit. A person may use both types of knowledge simultaneously, with some aspects of this knowledge being consciously accessible and others remaining outside conscious awareness. For this reason, measuring awareness is an important part of implicit learning research, as it helps researchers understand not only whether learning has taken place, but also what type of knowledge is supporting performance.

Demonstrating that learning has occurred is relatively easy, but showing that the knowledge responsible for that learning is unconscious is far more complex. For this reason, the assessment of awareness became an important issue in implicit learning research, leading researchers to develop several methods for measuring it. These include verbal reports, objective measures such as recognition or prediction tests, and subjective measures such as confidence ratings or assessments of the basis of participants' decisions (see e.g., Ziori, 2023).

One of the earliest methods was the use of verbal reports, in which participants are asked after the task to describe the rules or patterns they noticed. Although this method is simple and direct, it has important limitations, since people may possess knowledge that they cannot express verbally, may forget what they noticed during the task, or may not realise how this knowledge affected their decisions. Consequently, the inability to provide a verbal description offers relatively weak evidence that knowledge was unconscious (e.g., Dienes & Berry, 1997; Rebuschat & Williams 2012; Shanks & St. John, 1994).

Recognition and prediction tests provide a more structured alternative. Participants may

be asked to recognise information they have encountered previously or to predict specific features of novel stimuli. These measures can show whether some knowledge is consciously available, but they cannot determine how much of the original learning was implicit. Successful recognition or prediction may reflect explicit access to some knowledge but does not exclude the simultaneous contribution of implicit knowledge (e.g., Fu et al., 2008; Ziori & Dienes, 2012). Therefore, recognition and prediction tasks can be useful as complementary measures but cannot provide a clear test of implicitness.

A more sensitive method involves trial-by-trial confidence measures, which assess awareness at the time participants make each of their decisions (e.g., Dienes et al., 1995; Ziori & Dienes, 2006). The central idea is that people who are consciously aware of their knowledge should be able to distinguish between answers they know and answers they are simply guessing. So, if participants perform significantly above chance but report low confidence or guessing, this may suggest that their knowledge is affecting their performance without being consciously accessible. Dienes et al. (1995) proposed two criteria to assess the relationship between confidence and performance, namely the guessing and the zero-correlation criteria. The guessing criterion is satisfied when participants perform above chance on trials for which they report absolutely no confidence (i.e., they think the rely on pure guessing). The zero-correlation criterion focuses on the relationship between confidence and accuracy. If participants are aware of the knowledge guiding their responses, higher confidence should generally be associated with higher accuracy. If performance is above chance but confidence is unrelated to accuracy, this may indicate that participants are using knowledge without being consciously aware of it. Although confidence measures are considered more sensitive than verbal reports (e.g., Ziori & Dienes, 2006), they primarily assess awareness of whether a judgment is correct, rather than awareness of the knowledge type responsible for the judgment. Dienes and Scott (2005) distinguished between judgment knowledge, which is knowing whether a string is likely to be grammatical, and structural knowledge, which is knowing the patterns or relationships that make a string grammatical. These two types of knowledge may not be equally accessible to consciousness. For example, a participant may feel that a string is grammatical but be unable to explain what makes it grammatical. Therefore, confidence in an answer does not necessarily show whether the underlying grammatical structure is consciously known. To address this issue, Dienes and Scott (2005) developed a structural-knowledge attribution procedure that is particularly relevant to AGL research. Unlike confidence ratings, this procedure provides information

about how participants believe they arrived at their judgment. After each classification decision, participants report what they based their answer on, such as guessing, intuition, familiarity, recollection, or the use of a rule. Correct responses attributed to recollection or the use of a rule suggest that the participant has consciously accessible knowledge, whereas correct responses attributed to guessing, intuition, or familiarity may indicate that learning is influencing performance without conscious access to the underlying structure. This method provides a more direct way of examining whether the knowledge underlying their decisions is consciously accessible.

Taken together, the literature suggests that there is no single method for measuring awareness that can provide a completely definitive test of unconscious knowledge. Different methods capture different aspects of awareness and have different limitations. Verbal reports are vulnerable to failures of verbalization and memory, recognition and prediction tests assess explicit access but do not separate implicit and explicit contributions and confidence measures provide sensitive information about metacognitive awareness but may focus primarily on judgment knowledge. Nevertheless, in AGL studies, measures such as the Dienes and Scott's (2005) attribution procedure can be particularly informative because they provide insight into the basis of participants' grammaticality judgments. Overall, contemporary research increasingly treats implicit and explicit learning as interacting rather than completely independent processes. The main question is consequently not simply whether learning is "implicit" or "explicit," but what type of knowledge has been acquired in a certain condition or by specific groups of participants, how accessible that knowledge is to consciousness, and how different forms of knowledge contribute to behaviour.

Evaluating the robustness of implicit learning

One of the central claims about the properties of implicit learning is that it constitutes a robust and evolutionarily fundamental ability. The fact that it allows individuals to extract patterns from their environment without deliberate effort led Reber (1993) to propose that this form of learning may reflect an older evolutionary system that emerged prior to conscious reasoning and problem-solving. From this perspective, implicit learning would be expected to remain comparatively stable across development and be relatively unaffected by cognitive or neurological difficulties. This proposal has motivated a substantial body of research examining whether implicit learning is indeed resistant to individual differences and impairments. On the whole, research provides considerable support for its robustness,

while also revealing important limitations.

Developmental evidence provides compelling evidence that implicit learning is a fundamental ability present from very early in life. For example, Saffran et al. (1996) showed that 8-month-old learners were sensitive to subtle statistical relationships between syllables after only brief exposure to a continuous artificial speech stream. This capacity does not appear limited to language or to a particular developmental stage. Infants show similar sensitivity to statistical structure in musical tone sequences (Saffran et al., 1999) as well as in sequences of visual shapes from as early as 2 months (Kirkham et al., 2002). Notably, Teinonen et al. (2009) found that even sleeping neonates showed sensitivity to transitional probabilities between syllables, suggesting that the ability to detect and extract statistical patterns embedded in speech may be present from birth and may serve as one of the earliest building blocks of language acquisition.

Other studies on age-related change in implicit learning suggest that this cognitive ability remains broadly functional despite aging. For example, Bennett et al. (2007) found that both younger and older adults were able to learn subtle, higher-order sequential structure, even if to a lesser degree, without explicit awareness. Similarly, Verneau et al. (2014) found that older adults' implicit learning was comparable to that of younger adults, in clear contrast to their explicit learning, which was selectively impaired, while Howard et al. (2004) found intact contextual cueing skills in healthy older adults. Together, this evidence suggests that implicit learning mechanisms are relatively resilient to the effects of normal ageing, even when explicit learning processes decline.

Implicit learning abilities have also been demonstrated in non-human primates, supporting the possibility that some mechanisms underlying this form of learning have deep evolutionary roots (Hauser et al., 2001; Toro & Trobalón, 2005).

The proposed robustness of implicit learning has also been examined in relation to individual differences in intellectual abilities. Research has found little connection between intelligence and performance on implicit learning tasks (e.g., Danner et al., 2017; Kalra et al., 2019; McGeorge et al., 1997; Reber et al., 1992), supporting Reber's (1993) view that implicit learning does not rely strongly on the higher-level cognitive processes required for explicit learning. This pattern was often taken as evidence that implicit learning operates largely independently of general cognitive ability, reinforcing the broader claim that it constitutes a robust, low-level learning system relatively insulated from individual variation.

Although this body of evidence has contributed to the idea that implicit learning might

be resistant to individual differences, this strong interpretation has increasingly been questioned. Several studies have reported meaningful variation in implicit learning performance, linking it to factors such as intellectual ability, executive functions, age, and personality characteristics (e.g., Danner et al., 2011; Fletcher et al., 2000; Pedraza et al., 2024; Kaufman et al., 2010; Lukács & Kemény, 2015). These findings do not necessarily contradict the idea that implicit learning is robust; rather, they suggest that robustness should not be equated with complete independence from individual characteristics. Implicit learning may be relatively resistant to individual differences while still being shaped, at least to some degree, by the cognitive resources, developmental profile, and broader characteristics of the learner.

Evidence from neurodevelopmental populations provides an important further test of Reber's proposal, examining whether implicit learning can remain preserved even when other aspects of cognitive functioning are affected. However, findings across neurodevelopmental conditions are mixed, suggesting that implicit learning may be preserved in some conditions but affected in others. For example, Barnes et al. (2010) compared children with Attention-Deficit/Hyperactivity Disorder (ADHD) and TD children on two implicit learning tasks. The ADHD group showed inconsistent learning of repeating sequences in the ASRT task, whereas their performance on the CC task was comparable to that of controls. These findings indicate that implicit learning in ADHD may be affected in some forms of implicit learning, while other types, such as implicit learning spatial of contexts, may remain intact. In another study, Inácio et al. (2018) found that children with dyslexia learned sequences of coloured geometric shapes as efficiently as control groups, with no significant group differences, suggesting that dyslexia does not involve a general deficit in implicit sequence learning. By contrast, Kahta and Schiff (2016) found evidence of poorer implicit sequential learning in adults with dyslexia. Although both groups learned a visual linguistic grammar under minimal training, the TD adults performed significantly better. Research in Down syndrome has similarly produced different findings. Vinter and Detable (2008) found that children with Down syndrome had comparable implicit learning performance to TD participants but benefited less from explicit learning and had greater difficulty consciously recalling information about the learning experience. By contrast, Bussy et al. (2011) found weaker implicit learning in individuals with Down syndrome using an SRT task, particularly after an intervening block of random trials. The same study found evidence of relatively preserved implicit learning in Fragile X syndrome, although some individuals did not appear to learn the sequence.

Taken together, these findings show that implicit learning is not uniformly impaired across neurodevelopmental conditions. Rather, performance can vary according to the condition, the type of regularity being learned, and the demands of the task. This variability is particularly important for autism spectrum disorder (ASD), which has become one of the most extensively studied neurodevelopmental conditions in the field of implicit learning.

Autism and the relevance of implicit learning

Autism spectrum disorder (ASD) is a condition with neurodevelopmental origins, shaped by a combination of genetic and environmental factors whose precise interplay is still not fully understood. The language used to describe autism has received increasing attention. Person-first language, such as *individual with autism*, puts the person before the condition, whereas identity-first language, such as *autistic individual*, recognises autism as an important aspect of a person's identity. Research has shown that preferences vary across autistic people, families, professionals, and cultural contexts. For example, Kenny et al. (2016) found substantial support for identity-first terminology among autistic respondents, whereas a large Dutch study reported a stronger preference for person-first language among autistic adults and parents of children with autism (Buijsman et al., 2023). Recent recommendations therefore emphasise respecting individual preferences rather than assuming that one form is appropriate for everyone (Buijsman et al., 2023; Martinez et al., 2025). In the present work, both person-first and identity-first terminology are used interchangeably.

Current diagnostic frameworks, such as the Diagnostic Statistical Manual, 5th Edition (DSM-5) of the American Psychiatric Association (APA, 2013), describe autism as a condition involving ongoing difficulties in social and interpersonal interaction, combined with restricted and repetitive behaviours, interests, or activities. These core features are seen across different cultures, and socioeconomic backgrounds, although there is substantial individual variation in their expression (e.g., Sharma et al., 2018).

Autism also varies considerably in intellectual functioning. Overall, roughly a third of individuals with autism meet criteria for intellectual disability or fall within this range of intellectual functioning, whereas autism is frequently accompanied by comorbid conditions such as ADHD, anxiety, and depressive disorders (e.g., Bougeard et al., 2021; Kilicaslan & Tufan, 2024). Communication and motor profiles both vary widely in autism. Language ability ranges from exceptional linguistic skill to minimal or absent speech, often shaped

by co-occurring conditions (e.g., Vogindroukas et al., 2022), while motor difficulties, though not a core diagnostic characteristic, are commonly reported and similarly show wide variation in severity (e.g., Piccolo et al., 2025). Beyond these features, autistic individuals often experience a range of other difficulties, including broader challenges with executive functioning (e.g., Tschida & Yerys, 2022), as well as difficulties recognising faces and interpreting facial expressions of emotion (e.g., Liu et al., 2025; Harms et al., 2010). More broadly, autism has also been linked to a shift in how the brain processes information, relying more on basic, perception-level processing rather than on higher-level, integrative thinking (e.g., Bernhardt et al., 2025).

Many of the abilities that prove difficult for autistic people, including language, social understanding, perceptual processing, and motor skills, are acquired gradually and largely without conscious effort, through repeated exposure to regularities in the environment. This observation has made implicit learning a central focus of autism research, raising the question of whether differences in detecting and learning such regularities might help explain some of the difficulties associated with the condition. If people with autism show a broad difficulty with implicit learning, this could limit their ability to acquire the patterns underlying language, social interaction, motor coordination, and everyday behaviour more generally. If, instead, implicit learning in autism is largely preserved, these difficulties are less likely to reflect a general learning impairment, and may instead relate to other factors, such as the nature of the information being learned or to the particular demands of a given learning task. In the latter case, implicit learning might even function as a compensation mechanism for difficulties presumably originating from a conscious system. As in other neurodevelopmental conditions, the evidence in autism remains far from conclusive, with studies reporting preserved, impaired, and even enhanced implicit learning across different autistic samples and tasks. Possible reasons for this inconsistent pattern are considered in what follows.

Mapping implicit learning in autism

Although research on implicit learning in autism has expanded considerably in recent years, the findings remain difficult to reconcile into a coherent picture. The largest body of evidence comes from studies using variants of the SRT task, which assesses the implicit acquisition of sequential motor patterns. Most of these studies report intact learning in autistic participants relative to TD comparison groups (e.g., Barnes et al., 2008; Brown et al., 2010;

Nemeth et al., 2010; Pesthy et al., 2023; Sharer et al., 2015; Travers et al., 2010; Treves et al., 2024; Zwart et al., 2017, 2018). By contrast, Mostofsky et al. (2000) reported clear impairment on this task in an autistic sample. A third pattern has also emerged, with some studies reporting that participants with autism are able to learn the underlying sequences, but do so more slowly, less robustly, or via seemingly different mechanisms than TD participants (e.g., Gidley Larson & Mostofsky, 2008; Travers et al., 2015).

A further body of work has relied on CC paradigms, which test the implicit learning of repeated spatial layouts to facilitate visual search. Here too, findings diverge depending on study and testing conditions. Intact contextual cueing has been reported in several samples (e.g., Barnes et al., 2008; Brown et al., 2010), suggesting that individuals with autism can pick up spatial regularities from repeated exposure. In another study, Kourkoulou et al. (2012) found that autistic participants showed faster recognition on repeated relative to novel trials, benefiting from contextual cueing in a manner comparable to TD participants, although they responded more slowly overall, particularly on novel trials. Using a similar task, Travers et al. (2013) found that adolescents and young adults with autism showed reduced implicit learning from stimulus-identity cues, but their contextual learning improved to typical levels when spatial configuration cues were also provided. By contrast, Xie et al. (2024) found that autistic children showed implicit learning with stimulus-identity cues alone, but not when identity and spatial cues were combined, suggesting that the integration of multiple contextual cues may pose difficulties for implicit learning in autism.

Evidence from prototype category learning tasks presents a comparatively more consistent picture of impairment. Gastgeb et al. (2012), Klinger and Dawson (2001), and Klinger et al. (2007) all reported reduced prototype category learning in participants with autism compared to TD controls. Schipul and Just (2016) offer a partial exception, reporting that, while their autistic participants did eventually form category representations, learning proceeded more slowly than in TD participants.

Studies using probabilistic category learning paradigms have also produced mixed results. Brown et al. (2010) reported intact performance, with autistic participants accumulating probabilistic associations at a rate comparable to TD participants. By contrast, in a similar task, Scott-Van Zeeland et al. (2010) found that children with autism showed weaker learning and blunted reward-related brain activity than TD children, most markedly for social feedback. However, in another study, Solomon et al. (2011) suggested that although adults with autism performed relatively well on a probabilistic task, they exhibited a distinct

learning pattern and were slower learners overall.

Findings from AGL tasks remain especially limited, with only two known studies examining this form of implicit learning in autism, and with conclusions that do not coincide. Klinger et al. (2007) found that TD participants significantly outperformed high-functioning autistic participants on an AGL task, suggesting a genuine difficulty in extracting abstract structural regularities. By contrast, Brown et al. (2010) who also recruited high-functioning autistic individuals, found no differences between autistic and TD participants in AGL, suggesting that people with autism can extract this kind of abstract structural regularity just as effectively as TD individuals.

Notably, two studies resulted in enhanced implicit learning in autism. Virag et al. (2017), found that autistic participants outperformed TD participants in an alternating SRT task, while Roser et al. (2015) reported a comparable advantage on a visuospatial implicit learning task, with autistic adults showing greater accuracy than TD adults, although this advantage was not observed among children.

Collectively, the findings provide no clear evidence of a consistent pattern of impairment or preservation in implicit learning in autism, with outcomes differing across studies, tasks, and experimental conditions.

Considering possible sources of divergence

The mixed pattern of findings reviewed above raises the question of what factors might account for it. Rather than pointing to a single explanation, it seems more plausible that the inconsistencies documented across studies stem from a combination of factors, with the most likely explanations considered below:

Restricted sampling across the autism spectrum. Much of what is currently known about implicit learning in autism comes from studies that capture only a limited range of the autistic spectrum in terms of intellectual and symptom profile. With only few exceptions (Gordon & Stark, 2007; Klinger & Dawson, 2001), the large majority of studies have recruited high-functioning autistic participants, typically alongside average or above-average intellectual functioning. Individuals with more pronounced intellectual or symptom-related impairments are correspondingly underrepresented. Given the heterogeneity of autism, and because intellectual ability and symptom severity are both central to understanding how skills vary across the spectrum, this narrow sampling means that current findings likely

capture only a partial view of implicit learning across autism as a whole, rather than a representative one. Findings form the broader implicit learning literature provide some reason to expect that intelligence is not a major determinant of implicit learning ability (e.g., Danner et al., 2017; Kalra et al., 2019) even among people with intellectual disability (e.g., Merrill et al., 2014; Vinter & Detable, 2003). There is also some indication that implicit learning does not vary systematically with symptom severity, at least among individuals within the high-functioning range (e.g., Brown et al., 2010; Travers et al., 2010, 2013; Xie et al., 2024; see also Pesthy et al., 2023; though Schipul & Just, 2016, and Travers et al., 2015, report exceptions to this). Even so, the fact that so few studies have included individuals outside the high-functioning range, the existing conclusions may generalise only to a specific subgroup of the spectrum. Alongside this, IQ-matching procedures commonly used to equate autistic and comparison groups are themselves methodologically problematic, since the standard intelligence measures used for this purpose have been shown to systematically underestimate cognitive ability in autistic individuals (e.g., Nader et al., 2016), raising questions about how well "matched" these groups really are.

In short, restricted sampling across people with autism means that current conclusions about implicit learning in autism, however robust they may appear, speak primarily to one segment of a highly heterogeneous population, leaving open how well they would hold for autistic individuals with lower intellectual functioning or more pronounced symptom profiles. This gap in implicit learning research with low functioning participants with greater symptom severity was a strong motivation for the first study of this thesis.

The role of task demands. A further source of inconsistency may lie not in who was tested, but in what kind of implicit learning was tested. The tasks used across this literature differ substantially in their structure and processing demands, and these differences may themselves account for some of the divergent findings reviewed above. For example, SRT tasks, which show the most consistently intact performance in autistic participants, place relatively low demands on the learner, requiring mainly the detection of a single repeated sequence through motor output. By contrast, category learning tasks, including prototype category learning and AGL tasks, require abstracting a general structure (i.e., a category prototype, or an underlying grammar rule) across exemplars, rather than simply tracking a fixed, repeating pattern. Studies of prototype category learning have generally reported impairments in autistic groups.

This aligns with several studies which report not only reduced or atypical categorisation

skills in autistic samples, but also difficulty applying learned knowledge to novel situations, pointing to atypical generalisation abilities in autism as well (e.g., Bott et al., 2006; Church et al., 2015; Froehlich et al., 2012). Evidence from AGL tasks, however, remains limited, which is a surprising gap given how much AGL tasks could potentially offer to the field, since performance on these tasks can shed useful light on the acquisition of a range of complex skills, including categorisation, and generalisation of knowledge. In all, it is possible that implicit learning performance in autism is less affected by pattern detection per se, and more affected by the specific demands of the task. Further research using implicit category learning tasks, and AGL in particular, may help clarify whether the existing findings reflect selective difficulties, rather than a broader impairment in detecting regularities.

Insufficient measurement of awareness. A second, closely related limitation concerns how or whether studies have verified that the knowledge observed was genuinely implicit, rather than supported in part by conscious, strategic processes. Despite the importance of distinguishing between the two types of knowledge, the majority of existing studies have either omitted awareness measures (e.g., Gordon & Stark, 2007; Mostofsky et al., 2000) or relied on measures with known limitations. For example, Brown et al. (2010) and Pesthy et al. (2023) have based their conclusions on participants' spontaneous verbal reports, an approach long criticized for underestimating conscious knowledge that participants either fail to mention or struggle to articulate. Others have relied on recognition or prediction tests instead (e.g., Treves et al., 2024; Xie et al., 2024), which are typically framed as more objective but carry the opposite problem; because these tasks require explicit responses, above-chance performance on them does not cleanly rule out implicit contamination, making it difficult to isolate what portion of performance reflects implicit vs explicit knowledge. None of the reviewed studies have used awareness measures sensitive enough to convincingly separate the two forms of learning. Since implicit task performance can reflect the combined influence of conscious and unconscious processes, this widespread reliance on insufficiently sensitive measures represents a substantial gap, one that plausibly accounts for at least part of the inconsistency documented above. All three studies of this thesis aim to avoid the above obscurity by using more sensitive measures developed to disentangle implicit and explicit knowledge.

Beyond IQ and symptom severity. Although the narrow sampling described above remains an important limitation, neither IQ nor symptom severity has emerged as a reliable explanation for the discrepancies documented across implicit learning literature in autism,

at least within the high-functioning range that most studies have examined. This raises the possibility that other individual differences, closely tied to the specific characteristics of autism itself, may be responsible for at least part of the inconsistent pattern of findings. Prior research in this field, however, has focused mainly on the presence or severity of core autistic traits, or on simple group-level comparisons between autistic and TD participants, overlooking how implicit learning performance might vary as a function of other characteristics specific to autism. The absence of reliable relationships with intellectual ability and symptom severity indicates that other individual differences associated with autism may be more relevant to understanding these inconsistencies. The present thesis therefore considers two such factors, namely the processing tendencies across global and local levels and the social relevance of the information being learned.

Global vs local processing as a potential source of variation

One individual characteristic that may be relevant to implicit learning is individual processing tendencies, namely the extent to which a person tends to process information at a global level, focusing on the overall picture, or at a local level, focusing on specific features and details. Evidence from TD groups provides some support for this possible relationship. For example, individual differences in global vs local processing have been associated with differences in implicit learning (Kiyokawa et al., 2012) and implicit memory (Hine & Tsushima, 2018), suggesting that the way information is processed may affect implicit skills.

Global–local processing tendencies have been of particular interest in research on autism, as differences in how autistic individuals process global and local information have been proposed as one aspect of the cognitive profile associated with autism (Frith & Happé, 1994; Happé & Frith, 2006; Mottron et al., 2006). Theories such as the Weak Central Coherence (WCC, Frith, 1989) and the Enhanced Perceptual Functioning (EPF, Mottron et al., 2006) theory both suggest that individuals with autism are expected to show a preference for local processing although their predictions differ. The WCC account proposes a reduced processing of global information in autism, while the EPF framework suggests that global processing remains intact but may receive lower emphasis compared to local processing.

However, research findings regarding global vs local processing in autism remains mixed. For example, Koldewyn et al. (2013) reported reduced global processing and increase attention to local elements in tasks where participants are not instructed to attend to a specific level. Another study by Neufeld et al. (2020) found reduced global processing

without evidence of enhanced local processing, while Van Eylen et al. (2018) suggested that group differences in processing tendencies between TD and autistic groups were relatively small and varied depending on task features and participant characteristics.

Processing tendencies may be particularly relevant when considering implicit learning in autism. Possible differences between autistic and TD individuals in how attentional sources are distributed across global and local information, could potentially contribute to differences in implicit learning performance. Previous work has reported findings consistent with this possibility. In particular, Kourkoulou et al. (2012) found that participants with autism gained knowledge in a CC task involving both global and local configurations, despite differences in response speed. These findings indicate that differences in global vs local processing do not necessarily harm implicit learning, but leave open the question of whether they may influence implicit learning outcomes.

In all, the existing literature provides a basis for considering global vs local processing tendencies as one possible source of variation in implicit learning in autism. However, the relationship between processing tendencies and implicit learning remains insufficiently understood. Given that implicit learning may depend on the information to which attention is allocated during learning, the present thesis considered processing tendencies as one potential factor contributing to variability in implicit learning in autism.

The role of social vs non-social information

The type of information being learned may be another source of variation in implicit learning in autism, particularly when that information is socially meaningful. It is well established that social knowledge develops primarily in an implicit manner, through repeated exposure to patterns embedded in social situations (e.g., Frith & Frith, 2012; Ivanchei et al., 2019; Lieberman, 2000). Therefore, social information may provide a particularly important context in which implicit learning operates. In autism, however, the processing of socially meaningful information may differ from that observed in typical populations.

Compared to TD groups, people with autism have frequently shown reduced attention to or less efficient processing of social stimuli, particularly faces, (e.g., Congiu et al., 2024; Gale et al., 2019; Vacas et al., 2021) while differences in the processing of non-social information appear less consistent (e.g., Hinz et al., 2024). Such differences may also have implications for implicit learning of social content.

Research examining implicit learning of social information in autism provides some

indications that learning from socially meaningful material may be more challenging for people with autism. For example, Scott-Van Zeeland et al. (2010) found reduced learning in autistic children in a paradigm involving both social and non-social outcomes, with particularly reduced neural responses during social learning, while Costea (2018) found evidence that participants could implicitly learn regularities from facial emotional expressions, although performance showed a negative relationship to autistic traits. More recently, Xie et al. (2024) found that children with autism could implicitly learn socially relevant cues when learning involved a single source of information, but showed reduced learning when social cues had to be integrated with additional contextual information. Importantly, only Scott-Van Zeeland et al. included a comparable non-social learning condition, so the available findings cannot establish whether these results reflect challenges with social information processing or broader difficulties in implicit learning in autism. Nevertheless, they suggest that the social relevance of the material may be associated with implicit learning performance in autism and highlight the need for experimental designs that compare social vs non-social conditions.

Overall, the existing literature provides a basis for considering whether the social relevance of the learning material may be a possible source of variation in implicit learning in autism. The present thesis addresses this possibility in Study 3.

Overview

Chapter 1 introduced the theoretical background underlying the present research, including the nature of implicit learning and its distinction from explicit learning, the range of methods used to assess conscious and unconscious awareness, and the evidence for implicit learning across both typical and atypical development. The chapter then reviewed the literature on implicit learning in autism specifically, highlighting the inconsistencies observed in relative work and their likely sources, including differences in participant characteristics, task demands, and the sensitivity of awareness measures used. It closed by introducing the two characteristics central to the present thesis, namely global vs local processing tendencies and the social vs non-social nature of learning material, and by setting out the rationale and aims of the three empirical studies that follow. The thesis then continuous with four further chapters.

Chapter 2 presents Study 1, which examined implicit learning in autistic and TD par-

ticipants using an AGL task. Unlike most previous work, this study included autistic participants representing a wider range of intellectual ability and symptom severity. A primary aim was to examine whether autistic individuals can acquire implicit knowledge from an artificial grammar, and whether this learning relates to IQ or symptom severity. Processing tendencies were assessed using a separate Navon task and examined in relation to AGL performance, while sensitive, trial-by-trial measures of awareness were used to distinguish implicit from explicit knowledge.

Chapter 3 presents Study 2, which builds directly on the findings, and addresses a methodological limitation, of Study 1. In this study, a GLOCAL AGL paradigm incorporated both global and local regularities, allowing learning at both levels to be examined directly rather than inferred from a separate measure. Because participants received no instruction to focus on either level, this design allowed their processing tendencies to be expressed during learning. As in Study 1, trial-by-trial awareness measures were used to assess implicit knowledge, while a recognition test provided an additional measure mainly of explicit knowledge at each level.

Chapter 4 presents Study 3, which extends the rationale of Study 2 by shifting the focus from the level at which information is processed to the type of information being learned. More specifically, this study examined whether the social vs non-social nature of the learning material influences implicit learning in autism and whether the social relevance of the stimuli constitutes a further condition under which implicit learning may differ between TD and autistic groups. Using an AGL paradigm in which social (faces) and non-social (colours) information were embedded within the same learning context, the study allowed learning from both types of material to be compared directly. As in Study 2, trial-by-trial measures distinguished implicit from explicit knowledge, allowing the study to ask whether social relevance constitutes a further condition under which implicit learning in autism and TD individuals may diverge.

Chapter 5 presents the General Discussion, summarising the findings of the three empirical studies. The chapter then considers the theoretical significance of the findings for cognitive psychology and autism research, before turning to their potential practical applications. The limitations of the thesis and the generalisability of its findings are discussed next, including the reliance on AGL paradigms, variation in sample characteristics across studies, and the absence of direct measures of the cognitive mechanisms proposed to underlie the observed patterns. The chapter closes with suggestions for future research and a

summary of the thesis's central contribution to understanding implicit learning in autism.

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Chapter 2

Study 1

Implicit learning in children and adolescents with and without autism spectrum disorders: Exploring the effects of individual differences

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Abstract

Implicit learning plays an important role in the acquisition of various skills that are often deficient in individuals with autism spectrum disorder (ASD). The present study examines the implicit learning ability of children and adolescents with ASD, by comparing it to that of a typical group of peers, using the Artificial Grammar Learning (AGL) task. Additionally, this study investigates whether the above ability is associated with individual characteristics, namely, intelligence quotient (IQ), ASD symptoms severity, and individual perception style (global/holistic or local/focused). The sample consisted of 20 individuals with mild to relatively severe ASD symptoms and 20 age- and gender-matched typically developing individuals (TD). The unconscious (implicit) nature of learning was assessed via a subjective measure, the "no loss gambling" method, which allows an unbiased evaluation of the confidence accompanying each judgement. The results provided evidence of implicit learning, which was preserved in the ASD group, although reduced relative to the typical group. Multiple linear regressions with interaction terms between Group and participants' scores on the Wechsler Abbreviated Scale of Intelligence (WASI), the Childhood Autism Rating Scale (CARS), and performance on a Navon-type task examined whether the possible relationships between each of the above scores and AGL and implicit learning differ in the two groups. Implicit learning was not significantly associated with IQ, ASD symptoms severity or individual perception style (except for perception style in terms of RTs for the TD group). These results confirm and extend earlier findings supporting the resilience of implicit learning to individual differences.

Keywords

Implicit learning, autism spectrum disorders, artificial grammar learning, subjective measures of awareness, individual characteristics

Implicit learning in children and adolescents with and without autism spectrum disorders: Exploring the effects of individual differences

Autism spectrum disorders (ASD) refer to a set of complex neurodevelopmental disorders characterized by lifelong difficulties in social development and social interaction as well as by patterned behaviors and repetitive routines (APA, 2013). Although poor social behavior is the most salient feature in autism, a large spectrum of cognitive, language, and sensorimotor impairments are also prevalent in these populations.

Implicit learning is a cognitive ability through which individuals obtain knowledge of complex regularities without conscious awareness or intention and without being able to describe the acquired knowledge (Reber, 1967). Given the well-established evidence that this complex learning process is, to a great extent, involved in the acquisition of social, language, and motor skills (e.g., Conway et al., 2010; Jurchiș & Dienes, 2023; Kaufman et al., 2010; Masters et al., 2013), which are often deficient in ASD, many studies have examined the potential association between implicit learning mechanisms and a range of difficulties in skills that are implicit learning-dependent. Similar hypotheses have been tested, although with mixed findings, for other neurodevelopmental populations, such as people with attention deficit hyperactivity disorder (e.g., Barnes et al., 2010; Pedersen & Ohrmann, 2018; Rosas et al., 2010), Down syndrome (e.g., Bussy et al., 2011; Salehi et al., 2019; Vinter & Detable, 2008), and dyslexia (e.g., Inácio et al., 2018; Kahta & Schiff, 2016; Pothos & Kirk, 2004).

Prior research on implicit learning in ASD: A brief discussion of limitations

A large part of current literature has reported intact implicit learning in ASD at various ages (e.g., Barnes et al., 2008; Brown et al., 2010; Izadi-Najafabadi et al., 2015; Kourkoulou et al., 2012; Müller et al. 2004; Nemeth et al., 2010; Pesthy et al., 2023; Sharer et al., 2015; Travers et al., 2010; Treves et al., 2024; Ward et al., 2021; see also Travers et al., 2013; for a relative meta-analysis see Obeid et al., 2016), confirming Arthur Reber's evolutionary-type theory, whereby implicit learning is described as a robust ability that is resilient to individual differences and various neurological deficits (e.g., Reber, 1993). However, other studies have found that people with ASD exhibit either impaired implicit learning (e.g., Klinger & Dawson, 2001; Klinger et al., 2007; Mostofsky et al., 2000; Scott-Van Zeeland, et al., 2010; see also Travers et al., 2013) or preserved but impoverished implicit learning

performance as compared to typically developing (TD) groups (e.g., Gidley Larson & Mostofsky, 2008; Gordon & Stark, 2007; Schipul & Just, 2016; Sharer et al., 2016; Travers et al., 2015).

In the majority of studies reporting intact implicit learning in ASD, participants had to perform visuomotor sequence learning tasks, such as the Serial Reaction Time (SRT) task (Nissen & Bullemer, 1987; see Pedraza et al., 2023 for a discussion on the contribution of both perceptual and motor processes to performance in SRT tasks). The available information from such research indicates that individuals with ASD have typical implicit visuomotor abilities (see Zwart et al., 2019 for an overview of studies using the SRT task in ASD). However, results on other experimental paradigms and forms of implicit learning are significantly fewer and provide a rather mixed pattern of findings. For instance, some studies have revealed deficits in tasks that involve implicit category learning (e.g., Gastgeb et al., 2012; Klinger & Dawson, 2001; Klinger et al., 2007; Schipul & Just, 2016), whereas others have found unaffected implicit category learning in ASD (e.g., Brown et al., 2010).

Categorization is a cognitive process through which people extract and integrate information into groups or categories, thereby being able to use and generalize previously acquired knowledge to novel stimuli and conditions. This function has a fundamental role in addressing the complexities of real-world situations, such as the acquisition of language or the understanding of social dynamics (e.g., Ferguson & Waxman, 2017; Liu & Holt, 2009; Plate et al., 2019), which are among the skills that are often impaired in people with autism. Many studies have reported deficits or atypicalities in the categorization abilities of ASD groups (e.g., Church et al., 2015; Ellawadi et al., 2017; Froehlich et al., 2012). For example, while individuals with ASD often demonstrate a proficiency in categorizing objects based on clearly defined (e.g., single-dimensional) rules, challenges often arise when categorization involves more complex relations among features (e.g., Klinger & Dawson, 2001). Moreover, ASD subjects have trouble generalizing knowledge to novel situations, which suggests a potential limitation in adaptive learning strategies among these populations (e.g., Froehlich et al., 2012).

One of the most well-known and frequently studied categorization tasks in the implicit learning field is the Artificial Grammar Learning (AGL) paradigm (e.g., Reber et al., 1991). In AGL tasks, participants first observe sequences of symbols (usually letters or geometric shapes), without knowing that these strings are constructed by a complex finite-state grammar. Next, participants are informed of the existence of rules and are asked to distinguish

between new sequences that follow or deviate from these rules. Performance in AGL tasks can provide useful information on the acquisition of many complex skills, like language, categorization, and generalization. Additionally, unlike most SRT paradigms which involve a mixture of sensory and motor components, the AGL task relies only on perceptual learning, and thus contributes to extracting a clearer picture of the nature of learning that remains intact or is impaired in a given experimental context. In general, the particular characteristics of implicit learning tasks play an important role in our comprehension of cognitive functions in individuals with autism, as highlighted in an engaging discourse between Nemeth and Janacsek (2011) and Pellicano et al. (2011). However, the application of AGL paradigms in ASD is sparse, a gap that the present study aims to fill, by examining whether individuals with ASD are able to integrate and transfer the more complex rules and feature associations involved in the AGL task as compared to the to-be-learned information in many typical categorization tasks. Considering the challenges which ASD individuals may face in extracting and integrating information from complex stimuli, as well as in generalizing and applying knowledge to new contexts, autistics' performance on the AGL task is likely to be influenced by the specific deficits outlined.

Sampling and other methodological limitations of previous research and differences between existing studies on implicit learning in ASD may be the main reason for the frequent instances of contradictory findings that necessitate further research in a topic with substantial scientific interest and practical importance. Existing findings and conceptualizations regarding implicit learning in ASD have relied mostly on data collected from populations with rather mild deficits, almost ignoring more severe ASD cases, and thereby depicting only part of the bigger, rather fuzzy picture of a highly heterogenous neurodevelopmental disorder. Intellectual ability and severity of symptomatology are essential factors in understanding the skills of diverse range of individuals within the autism spectrum. However, with the exception of Gordon and Stark (2007) and Klinger and Dawson (2001), most studies in the field have included individuals with high-functioning ASD or Asperger's syndrome, and high intellectual functioning (e.g., Barnes et al., 2008; Nemeth et al., 2010; Travers et al., 2010).

There is a relative consensus among researchers that implicit learning ability is weakly or not at all related to intelligence (e.g., Danner at al., 2017; Gebauer & Mackintosh, 2007; Kalra et al., 2019; Reber et al., 1991), even in cases where intellectual disability (ID) is

present (e.g., Atwell et al., 2003; Gordon & Stark, 2007; Merrill et al., 2014; Vinter & Detable, 2003; but see Fletcher et al., 2000). Moreover, there is some evidence that implicit learning is not affected by ASD symptom severity, at least for individuals with varying levels of symptom severity within the high-functioning range (e.g., Brown et al., 2010; Travers et al., 2010; Travers et al., 2013; see also Pesthy et al., 2023; but see Schipul & Just, 2016; Travers et al., 2015). However, by primarily focusing on ASD individuals with average or above-average intellectual abilities and less severe impairments related to the disorder, the generalizability of most of previous findings becomes restricted to specific subgroups within the autism spectrum. IQ matching between autistics and controls, a procedure that has frequently been applied in previous work in ASD, is a complex and often questionable operation that is strongly related with the different measures of intelligence used, which often underestimate intelligence in autistics (see Dawson et al., 2007). On a similar note, as Dennis et al. (2009, p. 6) point out, "differences in IQ between children with [neurodevelopmental disorders] and age-matched controls represent, not poor sampling, but preexisting, nonrandom differences beyond experimenter control". Consequently, "matching IQ to controls in children with a neurodevelopmental disorder (by child or by groups) creates unrepresentative groups" (p. 9).

Another shortcoming of previous experimental work regarding implicit learning in ASD is the inadequate use of measures for the distinction between explicit and implicit learning. Although some tasks are considered more implicit in nature, like the Alternating SRT (ASRT) task which has a probabilistic structure that is difficult to be acquired explicitly (see Vékony et al., 2022), it should be noted that, in general, task performance alone is not a sufficient indicator for the acquisition of implicit knowledge or the exclusion of the parallel existence of explicit knowledge. Hence, complementary measures of consciousness should help researchers confirm that learning was indeed achieved through implicit learning mechanisms and without the use of conscious awareness in a given condition. Furthermore, most studies that did use complementary measures of conscious awareness relied on rather insensitive measures. For example, Brown et al. (2010) and Nemeth et al. (2010; however, see Vékony et al., 2022 for the implicitness of the task used in the study) relied on participants' free reports, namely a measure of conscious awareness that has been strongly questioned for its validity (see e.g., Dienes & Berry, 1997; Shanks & St. John, 1994). Prediction and recognition tests used by Travers et al. (2010), Travers et al. (2013), and Scott – Van Zeeland et al. (2010) have also been subjected to criticism (e.g., Jiménez et al., 1996; Reber

et al., 1985), mainly for their rather low sensitivity to evaluate the impact of implicit learning processes on task performance due to the high possibility of contamination of explicit knowledge detected in these tests from implicit knowledge. The absence of a sensitive measure of implicit awareness remains a significant issue that challenges the conclusions from earlier experiments.

We suggest that the use of extra measures of implicitness that are free from the aforementioned limitations and have been tested for their validity in various studies could shed more light on the understanding of the implicit learning phenomenon in typical and autism spectrum populations. To the extent that different measures of the unconsciousness of knowledge provide similar patterns of results this could offer converging evidence for the validity of these methods.

Individual perception style in ASD

As mentioned above, Reber's evolutionary theory postulates that implicit learning is resistant to individual characteristics, an assumption that is not consistently confirmed by recent empirical evidence which increasingly shows individual differences in implicit learning tasks (e.g., Kaufman et al., 2010; Pedraza et al., 2024; Verburgh, et al., 2016). Individual perception style is a characteristic that is subjected to interindividual differences and refers to people's tendency to process information using either a holistic (global) or a detailed-focus (local) approach. There has been extensive research concerning the global vs local information processing in ASD, with two main theories dominating the endeavor to explain the cognitive processing differences observed in ASD, namely the Weak Central Coherence theory (WCC) and the Enhanced Perceptual Functioning theory (EPF). The WCC theory (Frith, 1989; Frith & Happe´, 1994; see also Booth & Happe´, 2018) suggests that individuals with ASD demonstrate a cognitive bias towards local processing and are expected to have difficulty in integrating information into a coherent whole. On a later version of the WCC theory, ASD individuals were suggested to show a default preference for local elements and reduced but not impaired global processing (Happe´ & Frith, 2006). The EPF theory (Mottron & Burack, 2001; Mottron et al., 2006) offers an alternative framework, emphasizing the strengths rather than the deficits of the condition. This theory proposes that individuals with ASD are more sensitive to local details and may use global processing optionally, whereas TD individuals are thought to have a mandatory preference for global processing. Despite their different foci, both the above theories posit that the local biases

observed in ASD participants are not due to a deficit in global processing, but rather to a preference towards local details.

Studies with Navon-type stimuli (i.e., small letters forming a larger one) have produced mixed findings regarding the processing of local details and wholes in ASD. For example, in Hayward et al. (2012) and Mottron et al. (1999), ASD participants demonstrated a global advantage in visual processing, whereas enhanced local biases were observed by Behrmann et al. (2006), and Mottron et al. (2006). Some authors suggest that global processing is intact in ASD, but when not instructed to attend to a specific level, ASD individuals may show a preference for local information (e.g., Koldewyn et al., 2013; Plaisted et al., 1999). Interestingly, a meta-analysis concentrating on global-local visual processing among individuals with ASD yielded results inconsistent with a pervasive deficit in global processing or a pronounced advantage in local processing (Van der Hallen et al., 2015; see the Discussion for more information on this study). Finally, in a more recent study by Soriano et al. (2018), children with ASD demonstrated preserved global processing abilities, but greater switching costs, particularly when they had to disengage from local stimuli and shift their attention to global ones. The above inconsistencies might be explained by the variability of experimental methodologies, sample characteristics and/or the heterogeneity of ASD population (Simons & Todorova, 2018).

While cognitive processing in ASD remains an open research area with promising potential for the development of appropriate training and rehabilitation programs, to date there is a research gap on the relationship between individual perception style and implicit learning in ASD. A noteworthy exception is the study by Kourkoulou et al. (2012) who investigated implicit learning in ASD employing a contextual cueing task. The results showed that individuals within the spectrum are capable of implicit learning from spatial contexts, adapting to both local and non-local biases. However, when attention was directed to local cues, ASD participants demonstrated a difficulty in responding to novel stimuli, a finding that the authors attribute to possible challenges in generalization or to a limited behavioral flexibility within the ASD population.

Existing research data on the above relationship come either from studies on typical populations or from studies on ASD, which however, have used only implicit memory tasks. Such research suggests that individual differences in (global vs local) perception style may affect implicit and/or explicit processing. Hine and Tsushima (2018) recruited two groups of TD individuals and assigned one of them to an implicit memory task and the other to an

explicit memory task. Following the memory test, participants were asked to complete a Navon task (Navon, 1977) in which they had to respond as fast as they could in the presence of Navon-type stimuli. Results demonstrated a strong correlation between perception style and implicit but not explicit memory, indicating that perceptual differences are more likely to affect implicit skills. Further analysis revealed that participants with a local perception style performed better on the implicit memory task in comparison to the explicit one. In an ASD study, Lebreton et al. (2021) found that the tendency of ASD individuals towards local processing interfered with both their implicit and explicit memory. More specifically, it was found that the local processing bias of individuals with ASD prevented them from demonstrating the global processing advantage that the TD group exhibited under implicit memory conditions and interfered with explicit memories that included details during recognition.

In response to the above research gap, in this study we used both an implicit learning task (i.e., AGL) and a perception-style measure aiming to gain a deeper insight into the possible impact of perception style on the cognitive mechanisms underlying implicit learning in typical populations and most importantly in the hazy landscape of ASD.

The present study

The main aim of the present research is to investigate how implicit (and possibly explicit) learning may be affected by autism spectrum conditions. To this end, we conducted an experiment using the AGL paradigm. Although AGL tasks have been extensively applied in implicit learning research, only two published studies have used this methodology in ASD groups.

Klinger et al. (2007) reported significant differences in an AGL task between TD and high-functioning ASD participants, with the former outperforming the latter. However, in the above study, it is not clear whether performance in AGL reflected implicit and/or explicit learning, as no additional measure of consciousness was applied. The IQ tests that were used as a measure of explicit learning cannot provide any information about the type of knowledge acquired during the AGL task. Contrary to the above findings, Brown et al. (2010), who also recruited only high-functioning ASD individuals, found no differences between TD and ASD groups in four different implicit learning paradigms, including an AGL task. To evaluate the product of learning, they provided post-task questionnaires, supporting that if knowledge was conscious then participants would have been able to report what they have learnt. However, this is not exactly correct. As Dienes and Berry (1997; see

also Dienes, 2012) point out, among other weaknesses, verbal reports may leave out a substantial part of conscious knowledge, as subjects may hesitate to report low-confidence knowledge, which plagues the validity of this measure of conscious awareness.

Relatedly, the second main aim of our work is to provide sufficient evidence of implicit (and/or explicit) learning, by assessing performance on the AGL task with more sensitive measures of awareness. For this purpose, we used the "no loss gambling" method, which was introduced by Dienes and Seth (2010) and was designed to reduce the feeling of risk associated with a false judgement. In particular, the methodology of "no loss gambling" allows one to measure participants' confidence on their responses, as it asks them to either keep their classification judgement and get a reward if it is correct (this decision corresponds to confidence of some degree over their judgement) or to bet on a card, which could offer them a reward on a purely random basis (this decision corresponds to pure guessing regarding their response). So, after each classification, participants have to provide a gambling decision by either betting on the card (when they feel like guessing) or by choosing to bet on their response (whenever they feel confident to some degree). Moreover, this method is considered more enjoyable and attractive, especially for children (cf. Applin & Kibbe, 2021; Ruffman et al., 2001) and adolescents, like the participants in our research, who might have had difficulty in fully understanding and reporting different confidence estimates in a verbal manner (e.g., "guess" vs "confident" estimates). Another advantage of the "no loss gambling" method is that it allows the measurement of (un)conscious knowledge on a trial-by-trial basis, which corresponds exactly to the confidence measure methodology introduced by Dienes et al. (1995), namely, the *guessing* and *zero-correlation criteria*, which have been used in many implicit learning studies with typical populations (e.g., Dienes & Perner, 2003; Dienes & Longuet-Higgins, 2004; Ziori & Dienes, 2008). The guessing criterion of unconscious knowledge is fulfilled when the amount of correct low-confidence judgments (i.e., guesses) is significantly higher than a chance level, which indicates that subjects have knowledge that they do not know they have. In contrast to the guessing criterion, the zero-correlation criterion includes accuracy of all confidence estimates and provides evidence of conscious or explicit knowledge when accuracy for high-confidence responses is greater than accuracy for no confidence (guess) responses, that is, the above mean difference is greater than zero. Thus, when both criteria are satisfied, as is the case in many implicit learning experiments, evidence of both implicit and explicit knowledge is provided. The above methodology, which to the best of our knowledge was

never before applied in ASD, allows a clearer distinction between the amounts of implicit and/or explicit knowledge involved in a given task, in that it is embodied as a part of the experimental procedure itself, in comparison to verbal reports which are applied at the end of the experimental task. In addition, previous research (Ziori & Dienes, 2006) that has compared the two confidence-based measures with free verbal reports in terms of their sensitivity in detecting the consciousness of knowledge has revealed an increased validity of the former in comparison to the latter.

Our final objective is to shed more light on the relationship of implicit learning with individual differences, that is, on a research area with rather mixed findings. As mentioned above, researchers have frequently provided evidence of a robust implicit learning system that is independent of individual variation (e.g., Choi et al., 2020; Danner et al., 2017; Gebauer & Mackintosh, 2007). However, a significant and increasing number of studies reports contrasting findings, which point to substantial individual differences in implicit learning (e.g., Janacsek et al., 2012; Kaufman et al., 2010; Pedraza et al., 2024; Verburgh, et al., 2016). For example, although Kaufman et al. (2010) found no correlation of implicit learning with general intelligence or working memory, they did find individual differences in implicit learning that concerned other cognitive abilities, such as academic performance and processing speed, as well as personality traits. Additionally, Janacsek et al. (2012) found age-related differences in implicit learning capacity, which declined with age. Similarly, a very recent study by Pedraza et al. (2024) has found a negative correlation of implicit statistical learning with executive functions, especially with verbal fluency and working memory, a finding that the authors attribute to either an updating of working memory representations involved in these cognitive functions or to accessing long-term memory representations, both of which may operate antagonistically with implicit learning.

It is the above pattern of mixed findings on the relationship between individual differences and implicit learning in general and in the research area of ASD in particular that motivated our final objective, which is to examine possible relationships between implicit learning in the AGL task and individual characteristics of participants, and in particular, IQ, autistic symptoms severity, and individual perception style (local vs global). More specifically, we examined the relationship between performance from the implicit learning task with the scores of two standardized tests, a scale that measures intellectual ability (WASI: Wechsler, 1999) and a rating scale of ASD symptoms severity (CARS: Schopler et al.,

1986), as well as with performance on a Navon task (Navon, 1977). To gain a more complete understanding of the relationship between implicit learning performance and ASD features, the experimental group included subjects with mild to more severe ASD symptomatology. Until now, only two published studies in the field have collected data from low-functioning ASD individuals. Klinger and Dawson (2001) found impaired prototype formation in a group of 12 low-functioning ASD children matched with a TD group for language comprehension mental age. Authors report a positive correlation between receptive language mental age and accuracy on the implicit rule trials but not prototype formation. Gordon and Stark (2007) conducted two experiments using SRT tasks in small samples of low-functioning ASD children with a wide range of IQs and found preserved implicit sequence learning in ASD participants regardless of their level of functioning, when extensive exposure and training was provided. As done in Gordon and Stark (2007; see also Müller et al., 2004) and contrary to many other relative studies (e.g., Brown et al., 2010; Nemeth et al., 2010; Travers et al., 2013), in the current study we did not try to control for IQ or obtain IQ-matched groups. Firstly, in agreement with Dennis et al. (2009), we suggest that variables, such as IQ, that act as attributes of specific neurodevelopmental disorders like ASD, should not be distinguished and isolated from other effects or characteristics of the disorder and should thus not be treated as covariates or enter any other matching procedure. Secondly, a primary interest of the present work lies in the comparison of individuals with an intrinsically heterogenous disorder, namely ASD, with an age- and gender-matched group on a learning type (i.e., implicit learning) that is very often found to be relatively independent of IQ (e.g., Danner et al., 2017; Kalra et al., 2019; Kaufman et al., 2010; Reber et al., 1991; but see Fletcher et al., 2000).

Another individual difference that might influence performance in a task that is perceptually based, like AGL, is people's strategies focusing on either global/holistic or local information. In a typical AGL paradigm, where subjects are exposed to stimuli presented at a single level of hierarchy, it may seem that individual perception style has no straightforward relationship to AGL performance. However, it has been shown that AGL performance may reflect different classification strategies, such as detecting rules or/and item similarities (e.g., Opitz & Hofmann, 2015; Pothos, 2007; Visser et al., 2009; Ziori & Pothos, 2015), which may, to a different degree, involve a more local or global information processing module. In the context of AGL, a rule may take the form of identifying the position of a

symbol at a particular place (e.g., the end of a string), which might be thought of as characteristic of a more local type of processing. By contrast, participants might rely on the global resemblance of trained and test strings. Thus, it is suggested that performance on AGL tasks relies on the ability of subjects to extract local regularities and/or make global similarity judgments. Of course, the present research design cannot distinguish between different knowledge structures in the AGL task; accordingly, the investigation of the relationship between AGL performance and global vs local processing is only exploratory and speculative in nature.

To test whether performance on the implicit learning task is associated with individual perception style (global or local), we also examined the relationship of the two groups' AGL performance and implicit knowledge with performance on a Navon task. To the best of our knowledge, this study is the first to explore the above relationship, which might open interesting paths towards a deeper understanding of implicit learning in ASD.

Method

Participants

Twenty ASD Greek-speaking individuals aged from 7.9 to 19 years were recruited from public schools and Creative Employment Centers for people with disabilities. Based on their medical record, all participants in the ASD group had been officially diagnosed by trained clinicians in public Diagnostic Assessment Centers. Additional psychiatric or neurological conditions served as an exclusion criterion. The control group included 20 age- and gender-matched TD individuals who had never received any diagnosis for psychiatric or neurodevelopmental disorders, including ASD. There were no significant differences in age, $t(38)=.53$, $p=.597$, $d=.17$, or gender, $x^2 =1.026$, $p=.311$, between the two groups. Participants' IQ performance was assessed using the Greek-Cypriot edition of the Wechsler Abbreviated Scale of Intelligence (WASI: Wechsler, 1999). The scale has been adapted and tested on a Greek-Cypriot population in Cyprus (Spanoudis & Tourva, 2012). Subjects with severe ID, namely a full-scale IQ of less than 36, according to DSM-IV (APA, 1994), were excluded, as they might not be able to meet the tasks' demands. Teachers and school psychologists completed the Childhood Autism Rating Scale (CARS: Schopler et al., 1986) for both groups. The CARS is a widely used rating scale to assess behaviors indicative of ASD following direct observation. Scores on CARS can range from 15 to 60, with scores lower than 30 indicating a non-autistic diagnosis. There were significant differences in Full-Scale

IQ, $t(38)$=- 6.45, p<.001, d= -2.04 (as well as in Verbal and Performance IQs, ps<.001) and CARS scores, $t(38)$= 20.30, p<.001, d=6.42, between the two groups. Table 1 presents the mean age, WASI and CARS scores for both groups. All participants had normal or corrected to normal vision and were able to understand the instructions and comply with the requirements of the experimental tasks.

Written permission to perform the experiments was granted by the Greek Ministry of Education prior to data collection. Approval from the Ethical Committee of the University of Ioannina was also obtained. Finally, parents provided written informed consent, while participants gave an informed assent.

Table 1. *Mean age, WASI and CARS scores for the TD and ASD groups*

	Age				WASI scores									CARS scores		
					Full Scale IQ			Verbal IQ			Performance IQ					
	N	M	SD	Range	M	SD	Range	M	SD	Range	M	SD	Range	M	SD	Range
TD	20	14.3	3.6	7.3-19.2	102.7	10.6	87.9-124.6	102	12.8	84.7-128	103.4	12.1	82.7-130.8	17.3	1.8	15-20.5
ASD	20	14.9	3.3	7.9-19.0	67.5	22	40.2-125.9	70.25	19.1	41.7-109.7	64.67	26.48	35.1-147.9	35.4	3.6	31-43.5

Apparatus and General Procedure

Stimuli of both tasks were displayed on a 14-inch laptop screen, which was placed approximately 50 cm in front of the participants. Both tasks were administered using PsychoPy3 Experiment Builder (Peirce et al., 2019). Responses were produced using a separate keyboard apart from the laptop keyboard. All participants were tested individually in quiet rooms, and each session lasted approximately 50 min.

The AGL Task

For the learning phase we created strings of stimuli following the structure of the artificial grammar used in Reber et al. (1991), with the difference that letters were replaced by clipart images of 5 cartoon creatures (see Figure 1) to make stimuli more attractive.



Figure 1. *An example of an image string used in the AGL task.*

Participants were asked to carefully observe, memorize, and then reproduce each of the 20 different strings presented twice in a random order, without receiving any feedback. Each string remained on the screen for 8 secs. Strings contained 3-8 clipart images of the 5 cartoon creatures which were also affixed to the separate keyboard on 5 different keys. The current stimuli may be considered socially relevant, in alignment with a growing body of contemporary research on implicit learning (e.g., Costea et al., 2023; Norman & Price, 2012; Ziori & Dienes, 2015; Ziori et al., 2014), which uses social and more ecologically valid stimuli, such as sequences of body postures, faces or facial expressions, instead of the traditional highly artificial stimuli. In particular, the current experimental material involves sequences of cartoon images with different body characteristics, postures, and gestures, namely sequences of behavioral patterns like those that are encountered in everyday life and provide us with cues for extracting rules and regularities that facilitate our understanding of human behavior and social interactions and shape our decisions. A gain from the use of such meaningful and naturalistic stimuli in implicit learning studies is that they increase participants' attention and engagement, which is of great importance given the facilitative effect of selective attention on implicit learning (see e.g., Eitam et al., 2009), an effect that is even more useful for individuals with deficits in cognitive and social functioning.

Participants received both oral and written instructions to complete the task, and special care was taken with less functioning ASD participants, employing the simplest language possible. Both groups managed to reproduce the training strings to a similar degree, indicating that the ASD group had no difficulty in comprehending the instructions to observe and memorize the strings. Before the beginning of the test phase participants were informed that the strings they had seen were generated by a set of rules. Next, they were instructed to look at a new set of 50 strings, half of which were grammatically correct while the other half contained rule violations. Participants were asked to decide which of the test strings followed the rules and which of them did not. Test phase trials were self-paced.

The "no loss gambling" method of Dienes and Seth (2010) was embodied in the test phase as a measure of awareness. For each string classification, participants had to provide a gambling decision as well. Thus, participants could choose to either keep their classification decision and get a reward (i.e., school material, such as pencils, crayons, erasers) in case they were correct or exchange their decision with a card, which again could offer them a reward if the right card was chosen. Rewards were the same for all participants in that all

participants could choose from exactly the same school material at the end of the experiment. In case they felt they did not know which of the two choices to make (i.e., keep their classification decision or choose a card), they were encouraged to exchange their answer with one of two cards that were placed on their right side. If they chose the card with the green back, they would gain the school material at the end of the experiment. If they chose the red card, they would neither gain nor lose anything. The cards were then shuffled, and participants proceeded to the next string.

Importantly, this design, whereby rewards are offered for both low- and high-confidence responses that are correct, minimizes any potential impact of individual differences in reward processing on implicit and explicit learning, which is of particular significance, especially given the documented alterations in reward sensitivity observed in individuals with ASD (see e.g., Keifer et al., 2021). Relatedly, the two groups of the current study demonstrated equal amounts of low confidence in their responses, with no participant in either group consistently opting to exchange their classification decision with a card (that is, simply anticipating a reward on a purely random basis) throughout the experiment. This suggests that both groups a) were equally motivated (or not) solely by reward anticipation and b) understood the instruction to either keep their response or exchange it with a card depending on their confidence to an equivalent degree. Furthermore, Dienes and Seth (2010) have shown that both no-loss gambling and verbal confidence ratings which entail no reward processes exhibit comparable levels of sensitivity in capturing individuals' awareness of their own knowledge.

The Navon Task

Following a short interval of about 10 min after the completion of the AGL task, both groups were asked to complete the Navon task. One participant from the ASD group withdrew from this task due to his conflicting schedule. The remaining participants were instructed to look carefully at the center of the screen where the words “Big” or “Small” appeared in Greek for 2000 msecs. After the presentation of a fixation cross for 1000 msecs, Navon-type stimuli created from three Greek letters (“Ν”, “Σ” and “Π”) (see Figure 2) were presented for 250 msecs each. Prior to the beginning of the task, we ensured that all participants were able to recognize the three letters, read the words “Big” and “Small”, and understand the instructions through practice with an example of a Navon-type stimulus.

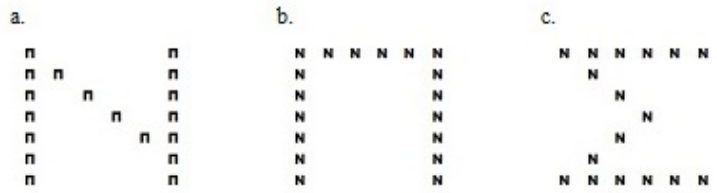


Figure 2. *Examples of the Navon-type stimuli used in the present study.*

Participants were required to select the letter on the global level when the word "Big" appeared or the letter on the local level when the word "Small" was presented. They were instructed to respond as quickly as possible, while the screen remained blank until participants gave a response. A 1000-msecs inter-trial interval separated a total of 72 trials, 36 for each level of processing (i.e., global or local). Letter stimuli were counterbalanced across levels, and the order of presentation was randomized for each participant. The possible demands that the instructions of the Navon task might pose on participants' working memory is not an issue of major concern, as they are not expected to affect the processing of the two types of stimuli (global vs local) to a different degree (see the Discussion for further information on this issue).

Statistical analysis

The significance level was set at .05 for all analyses. Independent-sample t tests were used for the comparison of the two groups (ASD vs. TD) in terms of their AGL performance and their consciousness criteria scores, and one-sample t tests were applied for the comparison of each group's performance against a chance level (of 50% for performance in the AGL task and the guessing criterion and 0 for performance in the zero-correlation criterion). The Benjamini-Hochberg method (Benjamini & Hochberg, 1995) was used to control false discovery rate (FDR) for multiple comparisons. Two-way ANOVAs on RTs and accuracy, with Group (TD vs ASD) as between-subjects variable and Level of processing (Global vs Local) as a repeated-measures variable were used for analyzing performance in the Navon task. Finally, three separate regression analyses with interaction terms (Group x IQ, Group x CARS, Group x Perception style in terms of RTs, Group x Perception style in terms of errors) were used for examining whether the contribution of individual characteristics (autistic symptoms severity, IQ, perception style) to AGL performance, the guessing criterion score, and the zero-correlation criterion score is differentiated by Group. Interaction terms were generated by multiplying the Group variable (coded as 0=TD, 1=ASD) with each of

the other independent variables. All continuous variables were mean-centered. Prior to entering the interaction terms into the models, multicollinearity was assessed. Tolerance statistics ranged between .32 and .44, while the Variance Inflation Factor (VIF) statistics were consistently low, ranging between 2.29 and 3.13. Hence, multicollinearity was not a concern.

Results

AGL classification performance

An independent-sample t test was conducted for the comparison of the two groups' overall performance in the AGL task. The above comparison revealed a significant difference between the two groups, $t(38)=-2.50$, p=.017, $d=-.79$, with the TD group outperforming the ASD group ($M=60.2\%$, $SD=7.01$ vs $M=54.9\%$, $SD=6.37$). Given the wide range in participants' age, we examined whether age impacts results as a covariate, through an ANCOVA which confirmed the significant difference between the two groups ($p=.015$). Two one-sample t tests were used to explore whether performance in the two groups exceeded a chance level of 50%. Both the ASD group, $t(19)=3.44$, $p_{adj}=.003$, $d=.77$, and the TD group, $t(19)=6.50$, $p_{adj}<.001$, $d=1.45$, scored above chance, a finding which indicates that both groups acquired some knowledge of the artificial grammar.

Consciousness criteria in the AGL task

The percentage of responses that were accompanied by low confidence (i.e., the percentage of bets on the cards) did not differ between the two groups, $t(38) = -1.08$, $p=.288$, $d=-.34$ ($M=41.3\%$, SD=17.4 for the ASD group and 46.7%, SD=14.1 for the TD group). So, the two groups relied on guess responses equally often, that is, they demonstrated equal amounts of low (and high) confidence in their responses. The above finding also implies that the two groups understood the instructions to the same degree, that is, all participants understood that they did not have to either keep their response or bet on the card all the time but responded as they felt in every single case.

The mean percentage of correct judgements when participants chose to bet on the cards (i.e., when they had low confidence) was used to measure unconscious knowledge by the guessing criterion. Knowledge is unconscious by the guessing criterion, when the percentage of correct low-confidence judgments exceeds a chance level. An independent-sample t test, $t(38)=-1.99$, $p=.054$, $d= -.63$, showed a marginally significant difference between

the two groups (M=56.4.2%, SD=7.3 for the ASD group vs M=61.5%, SD=8.87 for the TD group), with the ASD group being marginally less accurate than the TD group when they bet on the cards. An ANCOVA that controlled for age revealed a small gain in statistical significance in the difference between the two groups (p=.045). The mean value of correct low-confidence judgements was significantly higher than a chance level of 50% for both the ASD group, M=56.4% (SD=7.3), $t(19)$=3.93, p_{adj}<.001, d=.88, and the TD group, M=61.5% (SD=8.9), $t(19)$=5.81, p_{adj}<.001, d=1.30. Thus, both groups were able to make correct classifications when they thought they were guessing, which provides evidence of implicit knowledge by the guessing criterion.

The mean difference in accuracy between bets on the judgements (i.e., high-confidence responses) and bets on the cards (i.e., low-confidence responses) was used to determine whether the zero-correlation criterion of consciousness was satisfied. When the above difference is significantly higher than zero, evidence of conscious knowledge by this criterion is provided, whereas a value that does not exceed zero indicates the existence of unconscious knowledge.

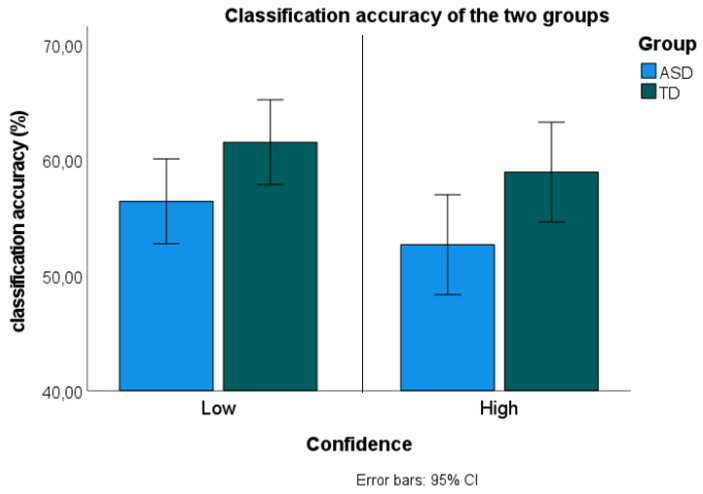


Figure 3. *Classification accuracy for the low-confidence responses (bets on the cards) and high-confidence responses (bets on the classification decisions) of the two groups.*

The independent-sample t test that compared the zero-correlation score in the two groups revealed no significant difference, $t(38)$=-.33 p=.74, d=-.10. The non-significant difference between the two groups was confirmed in an ANCOVA which controlled for age (p=.781). The overall mean value of the zero-correlation criterion (M=-3.17, SD=11.2) was not significantly higher than zero, $t(39)$=-1.79, p=.081, d=-.28, providing no evidence of

conscious knowledge. A 2x2 ANOVA on the percentage of correct responses with Group (TD vs ASD) as between-subjects variable and Confidence (High confidence vs Low confidence) as a repeated-measures variable (see Figure 3) is an alternative to the t test for estimating the zero-correlation score in the two groups, and thus yields exactly the same results (i.e., p=.74 for the two-way interaction and p=.08 for the difference in accuracy between high- and low-confidence responses).

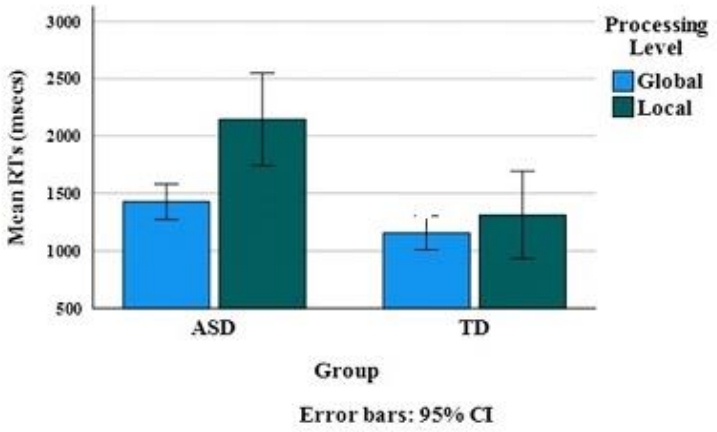
The above findings suggest that all participants, independently of group, acquired only unconscious knowledge by both criteria of consciousness, and that the TD group acquired marginally more implicit knowledge in terms of the guessing criterion than the ASD group.

Navon task

In order to explore participants' global/local biases, we used reaction times (RTs) for correct responses and percentage of incorrect responses (errors) in both levels of processing in the two groups. Following other studies that have explored the processing of hierarchical Navon-type material in people with ASD (e.g., Koldewyn et al., 2013; Mottron et al., 1999), RTs faster than 300 msecs or 3 *SD*s above the mean RT (for each level, in each group) were removed.

A two-way analysis of variance (ANOVA) was conducted on RTs, with Group (TD vs ASD) as between-subjects variable and Level of processing (Global vs Local) as a repeated-measures variable (see Figure 4a). This analysis revealed significant main effects of group, $F(1, 36)=11.08$, p=.002, η_p^2=.235, with the TD group responding faster than the ASD group, (M=1235, vs M=1786), and processing level, $F(1, 36)=12.44$, p=.001, η_p^2=.257, with the Global responses receiving shorter RTs than the Local ones (M=1285, SD=346 vs M=1707, SD=931). The two-way interaction was also significant, $F(1, 36)=5.17$, p=.029, η_p^2=.126. More specifically, the TD group responded much faster than the ASD group at the Local level of processing, $t(36)=-3.05$, p=.008, d=.99 (M=1312, SD=433 vs M=2146, SD=1135), than they did at the Global level of processing, $t(36)=2.58$, p=.014, d=.84 (M=1157, SD=320 vs M=1427, SD=325). Most importantly, the ASD group showed a much greater "global advantage" than the TD group, with the former group providing much shorter RTs for Global than for Local responses, $t(17)=-2.83$, p=.012, d=-.67 (1427-2146=-719) in comparison to the latter group, $t(19)=-2.76$, p=.013, d=-.62 (1157-1312=-155).

(a)



(b)

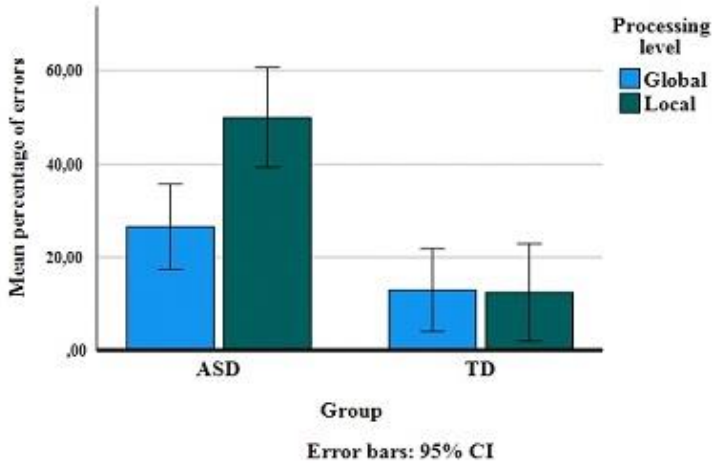


Figure 4. *The interaction between Group (ASD/TD) and Level of processing (Global /Local) (a) in RTs and (b) in errors.*

Incorrect responses that did not correspond to either of the two presented letters, namely responses that corresponded to the irrelevant third letter, were classified as "missed trials" and therefore were excluded from our analysis. This was done to ensure that the errors included in the analysis reflect individual perception styles related to the global/local levels, rather than other factors, such as possible attentional lapses or accidental selection of an unwanted key. For the ASD group, the mean percentage of missed trials was 3.9% for the Global level and 4.3% for the Local level, whereas for the TD group, the above percentages were 0.8% and 2.2% respectively.

A two-way ANOVA on participants' errors (see Figure 4b) showed a significant main effect of group, $F(1, 37)=42.20$, $p=<.001$, $\eta_p^2=.533$, with the ASD group making more errors than the TD group ($M=38.25\%$, vs $M=12.70\%$), and of processing level $F(1, 37)=4.16$, $p=.049$, $\eta_p^2=.101$, with the mean percentage of Global errors being significantly smaller than that of Local errors ($M=19.58\%$, $SD=20.52$ vs $M=30.71\%$, $SD=29.61$). A significant two-way interaction was also observed, $F(1, 37)=4.52$, $p=.040$, $\eta_p^2=.109$. In line with the RT results, the TD group made fewer errors than the ASD group at the Global level, $t(37)=2.15$, $p=.040$, $d=.66$ (M=12.94%, SD=14.99 vs $M=26.56\%$, $SD=23.49$), a difference that was even larger at the Local level, $t(37)=4.99$, $p=<.001$, $d=1.63$ ($M=12.46\%$, $SD=13.89$ vs $M=49.93\%$, $SD=29.78$). Further, the "global advantage" was observed only in the ASD group, $t(18)=-2.25$, $p=.037$, $d=-.52$ ($M=26.56\%$ for Global vs $M=49.93\%$ for Local errors), and not in the TD group, $t(19)=.103$, $p=.919$, $d=.023$ ($M=12.94\%$ for Global vs $M=12.46\%$ for Local errors).

In sum, the ASD group demonstrated an overall global advantage (in terms of both their RTs and errors), whereas the TD group exhibited a much smaller global preference and only in terms of RTs. The above pattern of findings contradicts both the WCC theory and the EPF theory regarding the processing style of individuals with ASD. Furthermore, the TD group outperformed the ASD group mainly in local rather than in global processing both in terms of RTs and in terms of errors.

Regression analyses

The predictors of the three regression models (for the AGL score, the guessing criterion score and the zero-correlation criterion score) were the following: Group, IQ, CARS, Perception style in terms of RTs, Perception style in terms of errors. Interaction terms with Group were added for each predictor. Recall that, in terms of the zero-correlation criterion, no evidence of conscious knowledge was obtained. The above score indicates the difference which arises by subtracting low-confidence accuracy from high-confidence accuracy; so, here we simply examine how each of the two types of accuracy relates to individual characteristics in the two groups. Following prior research (e.g., Hine & Tsushima, 2018; Mottron et al., 1999), we calculated an index of RTs by subtracting local RTs from global RTs and an index of errors by subtracting the percentage of errors in the local level from the percentage of errors in the global level. A negative value of each index reflected a global preference while a positive value corresponded to a local bias.

Two significant negative two-way interactions (Group x Index of RTs) suggested that perception style in terms of RTs was significantly related to AGL performance *B*=-.017, *SE*=.008, *p*=.040, as well as to implicit knowledge as measured by the guessing criterion, *B*=-.023, *SE*=.009, *p*=.022 (see Table 2), a relationship that concerned the TD group. In particular, the positive coefficients suggest that this group's knowledge of the AG structure and implicit learning may increase as the global processing bias decreases (*B*=.014, *SE*=.007, *p*=.063 and *B*=.021, *SE*=.009, *p*=.025 respectively).

Table 2. Multiple regression analyses for the entire sample

Variables	B	SE	Beta	T	p value
AGL performance, R^2 =.345, $F(9, 28)$=1.64, p=.153					
Group	-5.422	2.230	-.376	-2.431	.020
IQ (WASI)	-.059	.087	.200	.676	.504
Symptoms severity (CARS)	-.174	.549	-.230	-.316	.754
Perception style (Index of RTs)	-.001	.002	-.162	-.632	.532
Perception style (Index of Errors)	.039	.054	.182	.731	.470
Group x IQ (WASI)	.261	.187	.637	1.398	.173
Group x Symptoms severity (CARS)	1.211	1.181	.881	1.025	.314
Group x Perception style (Index of RTs)	-.017	.008	-1.689	-2.152	.040
Group x Perception style (Index of Errors)	.047	.111	.186	.420	.678
Guessing criterion score, R^2 =.288, $F(9, 28)$=1.26, p=.302					
Group	-5.020	2.679	-.298	-1.874	.069
IQ (WASI)	.037	.106	.109	.352	.727
Symptoms severity (CARS)	.172	.669	.196	.258	.798
Perception style (Index of RTs)	.001	.003	.122	.452	.654
Perception style (Index of Errors)	-.028	.065	-.111	-.426	.673
Group x IQ (WASI)	-.176	.227	-.368	-.775	.445
Group x Symptoms severity (CARS)	-.385	1.436	-.240	-.268	.790
Group x Perception style (Index of RTs)	-.023	.009	-1.986	-2.427	.022
Group x Perception style (Index of Errors)	.231	.135	.790	1.709	.099
Zero-correlation criterion score, R^2 =.333, $F(9, 28)$=1.55, p=.178					
Group	-1.570	3.749	-.070	-.419	.678
IQ (WASI)	.090	.145	.197	.622	.539
Symptoms severity (CARS)	-.127	.917	-.108	-.138	.891
Perception style (Index of RTs)	-.005	.004	-.326	-1.185	.245
Perception style (Index of Errors)	.095	.089	.284	1.064	.295
Group x IQ (WASI)	.711	.294	1.111	2.417	.022
Group x Symptoms severity (CARS)	3.247	1.861	1.512	1.745	.092
Group x Perception style (Index of RTs)	.007	.012	.483	.610	.547
Group x Perception style (Index of Errors)	-.325	.175	-.830	-1.856	.074

A significant positive two-way interaction (Group x IQ) indicated a relationship between intelligence and zero-correlation scores, B=.711, SE=.294, p=.022, which concerned the ASD group. More specifically, the positive coefficient (B=.362, SE=.126, p=.013) indicates that the ASD group's high-confidence accuracy appears to increase with an increase in IQ scores.

None of the main effects and the remaining interactions were significant. The above findings suggest that IQ, autistic symptoms severity, and perception style in terms of errors cannot directly predict AGL performance and implicit learning for either of the two groups.

Discussion

The main purpose of this study was to investigate whether implicit learning, in the context of AGL, is impaired in subjects with ASD, a topic of scarce and contradictory research findings. For the measurement of the unconsciousness of knowledge, unlike previous work that relied solely on the main experimental task or on unsensitive measures, we used the "no loss gambling" method that has been shown to be a reliable method of detecting unconscious knowledge (see e.g., Dienes & Seth, 2010).

Results showed that although the learning was present in each group (i.e., it is preserved in ASD, even in lower-functioning autistics than those examined in most studies) the AGL performance of the ASD group was weaker than that of an age- and gender-matched TD group.

The comparison of the two groups' implicit learning ability allowed us to test the evolutionary-type hypothesis (see Reber, 1993), according to which implicit knowledge is expected to be resilient to neurodevelopmental disorders, as well as to individual characteristics, like intellectual ability, autistic symptoms severity, and individual perception style, which were examined in the current study. Overall, it was found that implicit learning was relatively resistant to ASD and to individual characteristics. The findings of this study are discussed in more detail in the sections below.

Implicit learning in ASD

The preserved but relatively impaired implicit learning that was found in our ASD group contrasts with the results reported by Klinger and Dawson (2001), Klinger et al. (2007), Mostofsky et al. (2000), and Scott-Van Zeeland, et al. (2010), who suggest that implicit

learning is impaired in ASD, but also deviate from several previous studies where performance of ASD individuals on implicit learning tasks was found to be equal to that of controls (e.g., Barnes et al., 2008; Brown et al., 2010; Travers et al., 2010; Treves et al., 2024). Our findings are closer to those reported by Gidley-Larson and Mostofsky (2008), Gordon and Stark (2007), Schipul and Just (2016), and Travers et al. (2015), in which ASD participants demonstrated preserved yet less robust implicit learning abilities in comparison to TD subjects.

A major reason for the differences between the findings of the present study and those of previous studies may be the composition of the ASD group with respect to their IQ. In the field of implicit learning research, former work has focused primarily on ASD individuals with average or above-average IQ who typically exhibit mild symptoms of the disorder. The current study is one of the few to include ASD individuals with low intellectual functioning and more severe ASD symptoms. Low-functioning individuals with ASD with low intellectual ability represent a substantial segment of the ASD population. The inclusion of subjects with these particular characteristics and their comparison with their age- and gender-matched peers allows a more comprehensive and inclusive understanding of the learning abilities and potential challenges within the wider autism spectrum, which may provide valuable insights on a research area that has received limited attention. Relatedly, by purposely not matching ASD and TD participants in terms of their IQ, the present study acknowledges and considers the complex nature of ASD, where intellectual abilities may vary across these populations. As already mentioned, this notion is in line with the perspective supported by Dennis et al. (2009), according to which variables such as IQ, should be treated as important, intrinsic components of neurodevelopmental disorders instead of being separated from other features of these disorders and treated as covariates or matching variables.

Presumably, a study design like the current one, which prioritizes the deeper understanding of the complex cognitive ASD profile by not including matching criteria based on intellectual abilities, may raise concerns regarding the existence of potential confounding variables. For example, executive functions (EF) have been identified as a significant factor to be considered in ASD studies, given a general executive dysfunction that many studies have shown to persist across development in individuals with ASD (see e.g., Demetriou et al., 2018 for a relative meta-analysis). Moreover, research has highlighted the influence of EF on performance in implicit learning tasks (e.g., Kapa & Colombo, 2014; Pedraza et al.,

2024), further emphasizing their importance as a potential confounding variable. For instance, Pedraza et al (2024) demonstrated a negative correlation between EF and implicit statistical learning, whereas Kapa and Colombo (2014) found that stronger EF processes lead to increased learning of an artificial language. In light of these considerations, future research should include measures of EF to evaluate their contribution to the implicit learning of individuals with ASD as compared to that of neurotypical individuals. Furthermore, social dysfunction, which is certainly more pronounced in low-functioning autistics, is a critical factor to be considered in cognitive experiments with ASD groups, especially in cases where an interaction with the experimenter is required. For example, the Interpersonal Distance Theory of ASD (e.g., Farkas et al., 2023; Farkas et al., 2024) underscores the role of the physical distance individuals wish to maintain in social interactions, suggesting that possible violations of the preferred interpersonal distance during an experimental condition may cause interaction difficulties between the experimenter and individuals with ASD, which potentially might affect cognitive functioning outcomes. In the present study, interpersonal (especially face-to-face) interaction was kept to a minimum and concerned the discreet presence of the experimenter that was required for the provision of the necessary instructions, where needed, for the execution of the tasks, which decreases the possibility it might have differentially affected participants' performance in the two groups. Most importantly, the above interpersonal distance was maintained consistently within and among participants. However, we propose that future studies, especially studies conducted in real-life settings that entail more social interaction, could explore possible associations between implicit learning performance in ASD groups and individual differences in social preferences, such as those highlighted by the Interpersonal Distance Theory of ASD. Of course, it should also be noted that since the present work aimed at comparing ASD participants only with age-and gender-matched TD individuals, our results may generalize to ASD (and TD) individuals with the general profile of our sample. Future research with a larger sample could investigate whether our findings are more broadly applicable, by using participants of varying cognitive abilities such as IQ. Thus, future work could test the generalizability of the current findings by comparing the ASD group with an IQ-matched TD group of a younger age or with an age-matched control group with intellectual abilities below normative expectations.

Another source of differences between the current results and those of previous studies

may originate from the measures used to assess the implicitness of knowledge. For the assessment of the unconscious and/or conscious nature of AGL, we used, for the first time in a study pertaining to the implicit learning in autism, the "no-loss gambling" method (see Dienes & Seth, 2010). The specific method allows the measurement of the unconsciousness of knowledge in terms of the guessing and zero-correlation criteria that have been widely used in typical populations. In terms of the guessing criterion, performance for the ASD participants when they bet on a purely random response (i.e., they bet on the cards) was marginally lower than that of the TD participants. However, the percentage of correct low-confidence judgments of both groups significantly exceeded a chance level, indicating that implicit learning is preserved even in ASD young people with mild to more severe symptoms. Similarly, the zero-correlation criterion analysis yielded additional evidence of implicit knowledge for both groups. Although the zero-correlation criterion has often detected some conscious knowledge (e.g., Dienes & Seth, 2010; Ziori & Dienes, 2008; Ziori & Dienes, 2006), in our study, learning for TD and ASD participants occurred without any conscious knowledge of the patterns involved. These findings agree with the results of the post-task interviews performed by Brown et al. (2010), which revealed that both the TD and ASD subjects were unable to express what they had learned from an AGL task or any of the four tasks that were administered in that study. Contrary to the results presented by Brown et al., as well as the findings of the present study, Klinger at al. (2007) suggest that ASD individuals use explicit learning as a compensating mechanism for the requirements of an implicit learning task in order to deal with their implicit learning difficulties. We argue that such conclusions should be considered with caution unless the contribution of explicit learning is sufficiently evidenced. In the study of Klinger et al., this conclusion was obtained by a correlation between AGL performance and the results of IQ tests. However, measures of explicit learning should optimally be incorporated in the main experimental task, enlightening the exact implicit and/or implicit nature of the processes participants rely on while performing the task.

The relationship of implicit learning with IQ, autism severity, and perceptual style

Apart from the neurodevelopmental disorder of autism, the present work examined the relationship between additional individual characteristics of our sample (i.e., autistic symptoms severity, IQ, and individual perception style) and implicit learning in order to provide a deeper understanding of implicit learning in ASD and the resilience of this evolutionarily

older type of learning. Our results showed no evidence of a relationship between intellectual ability and AGL performance. The only significant relationship was the one between the ASD group's IQ and their high-confidence knowledge and not their low-confidence knowledge, indicating the existence of two qualitatively different types of AG knowledge that are differentially affected by intellectual ability. Importantly, intelligence was not a determinant for the acquisition of low-confidence accuracy, namely implicit knowledge as measured by the guessing criterion, at least in the particular groups of the current study, thereby confirming the thesis of a resilient implicit learning system.

The present findings are in line with previous work by Gordon and Stark (2007), who found evidence of implicit learning even in low-functioning ASD participants with a below-average mean IQ and found no effects of intelligence on implicit learning performance for this group. The independence of implicit learning from intelligence in ASD groups has been attested by several previous studies (e.g., Brown et al., 2010; Kourkoulou et al., 2012; Travers et al., 2010; Travers et al., 2013), albeit not by all. In a study by Gastgeb et al. (2012), authors reported a positive relationship between intelligence and performance on an implicit category learning task in the ASD but not the TD group. A significant correlation between implicit learning performance and IQ was also obtained by Fletcher et al. (2000), who assessed the implicit learning ability of two groups of children, with and without ID. These findings suggest that intellectual ability, as measured by IQ, may have an influence on implicit learning abilities. However, intellectual ability is a broad capacity which may have an impact on a wide range of skills that in turn may affect different aspects of performance in implicit learning tasks that might tap more closely into either an explicit or an implicit component. For example, cognitive flexibility, namely the ability to switch between different rules or patterns during a task and apply them to novel stimuli is found to be related to intellectual ability in both ASD (e.g., Memari et al., 2013) and TD individuals (e.g., Colzato et al., 2006). Although cognitive flexibility is generally thought to be primarily associated with explicit knowledge, it may as well involve an implicit type of processing (Custers & Aarts, 2010; Fujino et al., 2017). In AGL, in particular, it has been shown that unconscious knowledge can be strategically controlled and flexibly applied (see e.g., Norman, 2015). Thus, in studies that support an association between IQ and performance in AGL tasks, lower intellectual abilities might, for instance, lead to a reduced unconscious (or conscious) control because of a reduced cognitive flexibility. Furthermore, some studies (e.g., Dawson

et al., 2007) have shown that Wechsler intelligence scales may underestimate the intellectual functioning of people with ASD. We suggest that further research relying on sensitive measures of consciousness and more intelligence tests could determine the exact nature and strength of the relationship between the intellectual ability and implicit learning of ASD people of varying IQs, as well as the degree to which other factors may affect this relationship.

In agreement with several previous studies (Brown et al., 2010; Travers et al., 2010; Travers et al., 2013; but see Schipul & Just, 2016; Travers et al., 2015), the severity of ASD symptomatology in the current study was found to be independent of implicit learning. It should be noted that low-functioning individuals with ASD often face significant challenges in cognitive, social, and sensorimotor functioning to varying degrees. Thus, the inclusion of autistics with a wide range of symptomatology in implicit learning experiments could provide a more complete picture of implicit learning abilities in ASD, allowing for a better evaluation of the ASD-related strengths and weaknesses and a more effective intervention that would target the needs of a wider range of individuals with this disorder.

In this study we made a first attempt to test whether individual perception style has an impact on implicit learning. Reaction time and error data from the Navon task showed that the ASD group was, generally, slower, and less accurate, compared to the TD group. This finding complies with the findings reported by Koldewyn et al. (2013) and Plaisted et al. (1999), but not with those reported by Hayward et al. (2012), who found no such group differences. Contrary to both the WCC and EPF theories, RT analysis revealed a global advantage for the ASD group in that they responded faster to global than to local stimuli. This finding is in line with previous experiments where ASD individuals showed a global processing bias in similar tasks (e.g., Hayward et al. 2012; Mottron et al., 1999) as well as in selective attention tasks where subjects were explicitly instructed to which level they should attend (Plaisted et al., 1999). ASD individuals made more errors when the stimulus appeared at the local level, confirming the global advantage for this group. By contrast, for the TD group, the global processing bias appeared relatively weak and was observed only in terms of RTs. The above findings suggest that TD individuals may have a rather balanced processing style, which allows an effective integration of both global and local information, whereas the ASD group demonstrated a difficulty in processing local components, a pattern consistently demonstrated in all analyses. One possibility is that the demands that Navon-type tasks may place on working memory capacity might affect the performance of ASD

individuals, particularly, given the high correlation between working memory and IQ (e.g., Giofrè et al., 2013; Gray et al., 2017). However, a potential working memory deficit of the ASD group is not expected to impact the main question of interest, which is whether the two groups have differences in global vs local processing, given that the instructions for responding to both global and local stimuli impose equivalent memory load. Relatedly, the meta-analysis of van der Hallen et al (2015) which compared perceptual processing between ASD and TD individuals found no group differences on global vs local processing depending on intellectual ability. Of course, since the present study was not specifically designed to thoroughly investigate these cognitive dynamics, future research could explore the interplay between perception style and other cognitive abilities, including working memory capacity and IQ in ASD populations.

In general, our results on global/local information processing in ASD contribute to a field marked by considerable variability across studies, an issue aptly highlighted by Van der Hallen et al. (2015), who particularly emphasize the impact of task requirements on the observed inconsistencies (see also the interesting debate between Nemeth and Janacsek (2011) and Pellicano et al. (2011) on the importance of the exact nature of the tasks used in ASD research, that is, a debate that may expand the scope of any discussion concerning learning processes in autism). Our findings are consistent with the general pattern of results from Van der Hallen et al.'s meta-analysis, which disproved the predictions of the WCC theory about a local processing bias and a global processing shortcoming in ASD (even though they revealed slower global processing in this group). Another study that disconfirmed the predictions of the WCC theory is the one by Kourkoulou et al. (2012). However, in contrast to Kourkoulou et al who found equal global vs local processing sensitivity of the ASD group in a contextual cuing paradigm, we found that ASD participants demonstrated a pronounced global advantage in our Navon task, a discrepancy that may be attributed to differences in the task demands of the two studies.

The present results revealed that AGL performance and implicit learning were related to perception style only in the TD group and only in terms of RTs, with their knowledge of the AG structure and implicit learning increasing as the global processing bias decreased. Thus, it seems that a processing type that focuses primarily on local elements rather than on the whole picture is associated with increased AGL performance and better implicit learning outcomes. More specifically, the TD group demonstrated an overall advantage in both global and local processing as compared to the ASD group. As already mentioned,

AGL may require the application of rule-based strategies, similarity-based strategies, or a combination of both. These strategies may require local and global information processing skills at a different rate, and benefit performance accordingly. Thus, it is possible that the ASD group performed worse than the TD group in the AGL task because of deficits in the mechanisms involved in perceiving more local-type information, an interpretation consistent with this group's reduced performance on the Navon task in comparison to that of the TD group, especially when they had to process stimuli presented at the local level. Perhaps, the ASD group's increased bias towards global processing may have resulted in a reduced ability to extract and use local regularities, impairing performance on the AGL task. In line with the above possibility, Kourkoulou et al. (2012) found reduced transferring of knowledge to novel stimuli under locally restricted processing. However, as already stated, our study examines the relationship between AGL performance and individual perception style on an exploratory and speculative basis. While our results suggest a potential link between reduced AGL performance of the ASD group and impairments in information processing, particularly at the local level, further research is needed in order to ensure that these findings are reliable across these populations and under varying experimental conditions. Future research could explore alternative tasks and methods that could better capture potential links between implicit and/or explicit learning, and individual perception style. Investigating such possible relations could be an interesting endeavor for authors who want to add information to an issue that has been barely considered in literature and could contribute to a deeper understanding of the implicit learning abilities and weaknesses of both ASD and typical populations.

Conclusions

Overall, our findings indicate that individuals with ASD, even those with low intellectual abilities, retain their ability to learn implicitly, despite their reduced performance when compared with TD individuals. The above differences between the two groups could possibly be attributed to factors such as intellectual ability and/or information processing mechanisms, however the relationships between individual characteristics and implicit learning observed in the present work were weak and generally insignificant, providing evidence of a resilient implicit learning system. We suggest that implicit learning research in autism could benefit from studies that would employ a variety of implicit learning tasks with dif-

ferent demands and would include a wide spectrum of individuals with different symptomatology and abilities, trying to elucidate both their commonalities and their differences under different learning conditions. Finally, further research on the role of a broad range of individual characteristics and differences in implicit and explicit processing in autism could clarify the exact nature, strengths, and constraints of skills and weaknesses in ASD that could benefit from an implicit or an explicit intervention training program.

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Chapter 3.

Study 2

Implicit global-local learning in young people with and without autism

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Abstract

Implicit (unconscious) learning ostensibly affects cognitive and social skills in both typical and atypical populations, such as those on the autism spectrum. Research into implicit learning in autism has yielded conflicting results, underscoring the need to explore factors that might influence their implicit learning. One such factor is processing style, specifically processing biases for either global (holistic) or local (detail-oriented) processing. In our experiment we investigated the potential role of processing differences in implicit (and explicit) learning performance in individuals with autism (n=20) and typically developing (TD) individuals (n=22), by using a Global-Local version of the Artificial Grammar Learning (AGL) task. Overall AGL performance and explicit knowledge yielded only a trend towards an interaction suggesting a greater global processing advantage in TD participants compared to participants with autism but no conclusive evidence. The above interaction was further observed in terms of implicit knowledge, with TD participants demonstrating higher levels of implicit structural knowledge compared to individuals with autism during global processing. Implicit knowledge between-group differences during local processing remain weak/inconclusive. Overall, our findings suggest interesting potential processing differences in the implicit learning between individuals with and without autism.

Keywords

implicit learning, global vs local, artificial grammar learning, individual processing biases, autism

Implicit global-local learning in young people with and without autism

Implicit learning refers to knowledge acquisition through passive exposure to complex patterns or regularities and without people's effort or even conscious awareness (e.g., Reber, 1967, 1993). Individuals engage in implicit learning without explicit instruction and without being able to state what they have learned. Importantly, this definition does not imply that conscious awareness is entirely absent at all stages of learning in tasks that aim to elicit implicit learning; rather, implicit and explicit learning processes commonly coexist and both support task performance (e.g., Dienes & Scott, 2005; Dienes & Perner, 1999). Prior to a phase of learning, in experimental tasks that study implicit learning, individuals receive no information about the existence of any structured regularities embedded in the task. For instance, in the training phase of the artificial grammar learning (AGL) task (Reber, 1967, 1993), one of the most extensively used implicit learning paradigms and the one also used in the present study, participants observe strings of symbols without knowing that these strings are constructed by some complex artificial grammar rules. Under such an unintentional mode of processing during training, learning may involve limited or no conscious access to the underlying structure, although learners may as well develop some conscious knowledge too. Following learning, in the test phase of the AGL task, people are asked to judge the grammaticality of new symbol strings. The conscious or unconscious status of the knowledge demonstrated in this phase is often assessed by subjective measures like Dienes and Scott's (2005) method, in which people are asked to report the strategy on which they based each of their responses, with results often providing evidence of some unconscious knowledge (e.g., Guo et al., 2013; Mealor & Dienes, 2013; Ziori et al., 2014). The consciousness of knowledge acquired in implicit learning tasks is also often judged by post-experimental direct tasks like recognition tests, which have been shown to be primarily sensitive to explicit item-specific (e.g., whole-item or chunk-based) knowledge (e.g., Batterink et al., 2015; Knowlton et al., 1992; Knowlton & Squire, 1996; Liu et al., 2023).

According to Arthur Reber (1967, 1992, 1993), who provided the first experimental claim of implicit learning via the AGL task, implicit processes are rather robust and are thus expected to show reduced variability with respect to individual characteristics including various neurological disorders. However, later studies have challenged Reber's views, suggesting that implicit learning may be subject to variation in people's traits and characteristics, including intelligence (e.g., Danner et al., 2011), executive functioning (e.g., Pedraza

et al., 2024), age (e.g., Lukács & Kemény, 2015), and personality traits (e.g., Kaufman et al., 2010). The notion that implicit processes may be affected by individual and developmental factors has directed researchers' interest towards whether this type of learning can also be affected by various clinical or neurological disorders.

One such condition is Autism Spectrum Disorder (ASD), namely a syndrome that encompasses repetitive behaviors and frequent deficits in cognitive functioning, social communication, language development, and sensorimotor skills, which begin early in life and vary widely in intensity. Numerous studies have extensively explored various aspects of this complex disorder, which is now recognized as a highly heterogeneous condition of varying severity and causes. In this paper, we use a mix of person-first (e.g., individuals/people with autism) and identity-first (e.g., autistic people/individuals) terminology when referring to ASD or to people with this condition, in alignment with the guidelines of recent research, in order to cover the different preferences of both professionals and individuals with this condition (see e.g., Buijsman et al., 2023; Kenny et al., 2016; Martinez et al., 2025).

Implicit learning has been studied for several decades; however, the research field that explores the implicit learning capacity in people with neurodevelopmental disorders, including autism, has increased considerably in recent years. The way implicit learning functions in individuals with autism may improve our understanding of this particular condition. For example, the possibility of implicit learning deficits could help explain why people with autism face difficulties in social interactions, communication and motor abilities, all of which are thought to depend on implicit learning processes (e.g., Conway & Pisoni, 2008; Jurchiș & Dienes, 2023; Reber et al., 2019; Reed et al., 2010).

Despite the increasing research interest on whether and how autism affects implicit learning skills, the evidence is still far from conclusive. A substantial number of studies have examined visuomotor implicit learning in autism, mainly by using serial reaction time–type paradigms. Their findings range from preserved implicit learning (e.g., Nagy et al., 2025; Nemeth et al., 2010; Pesthy et al., 2023; Travers et al., 2010; Treves et al., 2024) to reduced or delayed learning relative to TD groups (e.g., Mostofsky et al., 2000; Gidley Larson & Mostofsky, 2008; Gordon & Stark, 2007; Travers et al., 2015). These discrepancies have been interpreted in terms of task demands, learning rate differences, or developmental factors. Other studies have focused on contextual cueing paradigms, which assess the implicit learning of spatial regularities. Intact contextual cueing effects in autism have

been reported by Brown et al. (2010) and Kourkoulou et al. (2012), whereas later work suggests reduced or altered learning effects in autism under certain conditions (Travers et al., 2013; Xie et al., 2024). Notably, enhanced implicit learning performance in autism has been reported in a visuospatial implicit learning task by Roser et al. (2015), suggesting that under certain task conditions implicit learning may not only be preserved but even superior in individuals with autism. By contrast, studies with prototype learning tasks, which rely on abstraction across exemplars, have yielded evidence for impaired implicit learning in autism (Gastgeb et al., 2012; Schipul & Just, 2016), pointing to possible limitations on category learning mechanisms. Studies employing AGL paradigms have also produced mixed results, with evidence for intact (Brown et al., 2010), impaired (Klinger et al., 2007) or preserved but less developed (Ziva & Ziori, 2025) implicit learning abilities in autism.

Taken together, this diverse pattern of findings suggests that implicit learning in autism is not consistently impaired. Indeed, meta-analytic reviews show that, on average, implicit learning ability is preserved in people with autism (Foti et al., 2015; Obeid et al., 2016), while also emphasizing that the notable variability across studies, may stem from task characteristics and/or individual factors that may affect implicit learning performance of individuals with autism. Nevertheless, it should be noted that most of the above studies (with the exception of Ziva and Ziori, 2025) have inferred the presence of implicit knowledge relying solely on participants' performance in implicit learning tasks or have applied insensitive measures of awareness. For example, some studies (e.g., Brown et al., 2010; Nemeth et al., 2010; Pesthy et al., 2023; Roser et al., 2015) have drawn conclusions regarding participants' acquired knowledge based on their verbal reports, an approach that has been strongly criticized for not being sensitive enough to accurately capture conscious knowledge (see e.g., Dienes & Berry, 1997; Shanks & St. John, 1994). Other studies have used only prediction or recognition tests (Travers et al., 2010; Travers et al., 2013; Treves et al., 2024; Xie et al., 2024), which assess primarily explicit knowledge without providing information about the contribution of implicit processes in performance. Given that performance in implicit learning tasks typically reflects a combination of conscious and unconscious effects, the lack of sensitive measures is a significant limitation that may partly account for the mixed results observed in previous work.

Researchers aiming to explain the contradictory results of implicit learning studies in autism have examined whether implicit learning performance is varied due to specific characteristics/symptoms of the condition, which might vary between autistic groups across

studies (noting that there are inconsistencies in autism characterization in different studies). Current data suggest that the reported differences in the pattern of implicit learning performance detected in autistic and TD groups can neither be directly attributed to the main symptomatology of autism, regardless of its severity, nor to autistic individuals' intellectual abilities (e.g., Brown et al., 2010; Travers et al., 2010; Travers et al., 2013; Xie et al., 2024; Ziva & Ziori, 2025; but see Schipul & Just, 2016, and Travers et al., 2015 for exceptions regarding autism symptomatology, and Gastgeb et al., 2012 for an exception regarding the influence of IQ differences).

Considering the above conflicting results, further research would be useful as a means to disambiguate these discrepancies. In a very recent study, Ziva and Ziori (2025) suggested that exploring the role of a broader range of individual characteristics in implicit learning could possibly shed more light on the different patterns of implicit learning observed in neurotypical individuals and individuals with autism. They proposed that one such characteristic is individual processing style, namely the way individuals prefer to process information, either by focusing their attention on the whole picture (i.e., more global information) or on more detailed, local information. Given the various suggestions regarding attentional differentiation between individuals with autism and TD individuals, this approach offers promise to progress this debate, not in terms of whether implicit learning is generally intact in people with autism, but rather in terms of highlighting particular aspects of deficit vs competence. Presumably, implicit learning may vary across different kinds of perceptual processing; a pertinent distinction concerns global processing (i.e., attending to the big picture of a stimulus) vs local processing (i.e., attending to the details of a stimulus).

Whether differences between local and global processing affect implicit cognition has been attracting some attention. For example, Kiyokawa et al. (2012) reported that a group of Japanese students demonstrated a clear bias for global processing, displaying chance performance when it came to local processing, in a global-local version of an AGL task, like the one used in our study. By contrast, UK students exhibited comparable learning for both processing types. Pertinently, this effect persisted even when the structural knowledge they had gained was implicit in nature. Two more recent studies examined the impact of processing biases on implicit skills, specifically on implicit memory. Hine and Tsushima (2018) found that the implicit (and not the explicit) memory of their TD subjects was affected by individual perception style, such that participants who displayed a local processing bias relied more on implicit memory than those with a global processing style. In

another study, Lebreton et al. (2021) examined how the local processing tendency of individuals with autism affects implicit and explicit memory under global and local processing conditions. They found that, in the implicit memory condition, the local processing bias of the autistic group reduced their ability for globally directed processing, while in the explicit condition it impaired their ability to distinguish between stimuli with common characteristics.

Taken together, the above findings suggest that different processing tendencies may have an impact on competences related to implicit vs explicit processing.

Processing biases in autism and their role on implicit learning

As already mentioned, processing tendencies (biases towards global or local processing) may vary between individuals and reflect how people tend to perceive and analyze information, either through a holistic (global) or a detailed-oriented (local) perspective. A putative tendency of individuals with autism for local information processing is an idea supported by certain theories aiming to explain cognitive processing in autism, namely by the Weak Central Coherence (WCC) theory, introduced by Frith (1989; see also Happe´& Frith, 2006; Morgan et al., 2003) and the Enhanced Perceptual Functioning (EPF) theory postulated by Mottron and Burack (2001; Mottron et al., 2006). Although both theoretical frameworks propose that people with autism are expected to demonstrate a bias for local processing, the WCC theory predicts reduced global processing abilities in autistic groups as a result of deficits in central coherence, while the EPF model postulates that global functioning in autism is unimpaired, although a person with autism is likely to use global processing mechanisms less frequently.

Visuospatial perception in autism has been extensively explored, but with varying and inconsistent results. For example, a study by Chen et al. (2012) found that adolescents with autism showed enhanced local visual processing and slightly reduced global processing abilities compared to healthy controls, while Nilsson Jobs et al. (2018) found that young children that had received an autism diagnosis had superior performance on a local visual task but did not differ from other groups with no such diagnosis on global tasks. By contrast, a meta-analysis on the visuospatial skills in populations with autism indicates that the differences observed in the processing of holistic (global) and more detailed (local) information between subjects with autism and neurotypical subjects are minor (Muth et al., 2014). Individuals with autism appear to show a tendency for local information, albeit of a

small to medium magnitude. Similarly, another meta-analysis of studies of autistic groups aged 6–35 years suggests that information processing in autism is not that atypical: the results showed neither a widespread impairment in the processing of global information nor a superior performance in local processing for individuals with autism (Van der Hallen et al., 2015).

Other authors propose that the processing of global information remains unimpaired in autism, but local processing biases may be observed more frequently in tasks allowing participants to choose the preferred processing style. More specifically, in visuospatial tasks where there are no specific instructions asking participants to focus on a particular type of information (either global or local), individuals with autism appear to show a bias for local levels of processing and reduced global processing. (Koldewyn et al., 2013; Plaisted et al., 1999). Relatedly, Van Eylen et al. (2018) showed that, when it comes to controlled experimental conditions, the processing abilities of participants with autism were almost comparable to those of a TD group, although there may be some variation due to the nature of the task (see also D'Souza et al., 2016) and demographic factors like age and gender. Their results suggest a weak global processing deficit in autism and a consistent but not remarkable bias towards local features. In another study, Neufeld et al. (2020) found decreased global processing in subjects with autism but not enhanced local processing (for similar results see also Booth & Happe´, 2018; Nayar et al., 2017). By contrast, Bouvet et al (2014) found a local bias and intact global processing in autism using auditory stimuli with a hierarchical structure. In all, it seems that the differences in information processing between individuals with autism and neurotypical individuals are not consistent. However, most evidence seems to point to a relatively lower global advantage of autistic people compared to TD groups, most likely because of their local processing bias. Evidence for a crossover interaction is also supported, albeit by a limited number of studies and is highly dependent on specific task demands (e.g., Koldewyn et al., 2013; Plaisted et al., 1999).

A gap in the implicit learning literature concerns the fact that very little is known about the role of processing biases on how individuals with autism process information implicitly. Kourkoulou et al. (2012) showed that individuals in the spectrum were overall slower than a TD group in their responses in an implicit visual search task (see also Travers et al., 2013; Xie et al., 2024), but they were able to acquire some knowledge of the task, independently of whether it demanded learning from global or local spatial configurations. Notably, the

only known study that specifically explores global vs local information processing in implicit learning of individuals with autism vs TD individuals is Ziva and Zori (2025) – this study contradicted the expectations of both the WCC and the EPF theories. In this study, both groups showed a global processing advantage; however, the TD group demonstrated a weaker global processing bias and only in terms of reaction time and not accuracy. Furthermore, the TD group outperformed the autistic group in general and especially when local processing was required. Ziva and Ziori's findings indicate a possible connection between the decreased implicit learning performance of the autistic group and difficulties in information processing, mainly at the local level.

In Ziva and Ziori's (2025) study, participants first performed one of the most widely used implicit learning tasks, namely the AGL task (e.g., Pothos, 2007; Reber, 1967; Reber et al., 1991). After the AGL task, participants were instructed to perform a Navon task which measures peoples' processing biases toward global vs local features (or the whole picture vs the details) of a visual stimulus (Navon, 1977).

The autistic group had above chance AGL performance, but lower compared to that of the TD group. Results from the Navon task showed that the TD group demonstrated an advantage in both global and local processing compared to participants with autism, who struggled mainly with processing local elements. Most importantly, the authors reported a correlation between AGL performance and individual perception style for the TD group, with higher grammaticality performance being associated with a reduced preference for global processing. A possible interpretation of this finding may be that a processing orientation emphasizing local elements, rather than the global picture, could be linked to enhanced AGL performance, as AGL may (among other parts) involve the learning of detailed information like the learning of adjacent dependencies, which may be considered a more local type of processing. Hence, the observed bias of the autistic group toward global processing could potentially have impeded their capacity to do well in the AGL task.

To sum up, the limited existing knowledge of how individual differences in processing biases might influence implicit learning processes in populations with autism vs TD populations highlights a notable research gap in this specific area. This paper aims to provide new perspectives on implicit learning mechanisms and the way they might be differentiated between individuals with autism vs TD individuals, as a function of processing biases.

The present study

Ziva and Ziori's (2025) approach involved correlating results from two separate tasks, namely, one assessing implicit learning and one assessing individual processing biases towards global or local information. This presents an interpretative challenge, since global vs local tendency in one task does not necessarily translate to global vs local tendency in implicit learning and AGL specifically. Therefore, in the present study both global and local processing modes were included within the same task, by using a global vs local version in the same AGL paradigm. This experimental design allows us to examine whether individual processing biases may have a moderating role in artificial grammar learning outcomes, thereby filling a gap in the existing AGL research on the implicit learning of people with autism. If this is the case, then the discrepancies observed in earlier work on implicit learning in autism may, at least in part, reflect differences in task characteristics related to local vs global processing biases, rather than general implicit learning challenges for populations with autism.

We created a global-local version of the AGL paradigm using the GLOCAL letter sequences generated from two different artificial grammars from Tanaka et al. (2008). GLOCAL sequences were originally developed by Tanaka et al. (2008) as a method of examining the effect of attention biases within the AGL paradigm (see also Kiyokawa et al., 2012; Li & Shi, 2016). These sequences are composed of compound letters, following the concept introduced by Navon (1977). Each compound letter is comprised of a larger, global letter constructed from a collection of smaller, local letters. Consequently, as can be seen in Figure 1, a GLOCAL sequence may be perceived as one coherent sequence when seen as a global stimulus (e.g., NNΣTΣ) and simultaneously as a different sequence if one focuses on the details or the local level of each large letter (e.g., ΓMΓZZ). Note, for a neurotypical individual it may appear that processing on the global level is easier, however, there is evidence that participants with autism are more interested in (or just focus more on) the detailed structure.

Finally, in contrast to most previous studies that investigated implicit learning in autism relying only on participants' performance on implicit learning tasks or on insensitive measures of consciousness, we applied both a subjective measure used in many implicit learning studies and a prost-experimental recognition task. Doing an AGL task can lead to both (ostensibly) implicit and explicit knowledge. In the context of AGL in particular, learners may demonstrate knowledge of whether a sequence is grammatical or ungrammatical,

which is referred to as judgment knowledge, and knowledge of the specific features or regularities underlying grammaticality judgments, which is referred to as structural knowledge. Judgment knowledge has traditionally been assessed mainly using confidence-based measures that capture participants' awareness of the correctness of their responses (e.g., Dienes et al., 1995; Scott & Dienes, 2008; Ziva & Ziori, 2025). However, the presence of conscious judgment knowledge does not inform us at all on the consciousness of structural knowledge that led to a decision. More specifically, unconscious judgment knowledge suggests unconscious structural knowledge, but conscious judgment knowledge may be accompanied by either conscious or unconscious structural knowledge. In the present work we examine only the (un)consciousness of structural knowledge, as is done in many relevant implicit learning studies (e.g., Kiyokawa et al, 2012; Norman et al., 2016; Ziori et al., 2014), as our focus is on *what* participants know, namely on the knowledge the two groups acquired about the structure of global and local training sequences. To this end, we used a method widely used in AGL experiments, whereby participants are asked to report the rationale behind their classification judgments (Dienes & Scott, 2005). Moreover, given that knowledge of the artificial grammar structure may encompass awareness of specific items or fragments of items (Dienes & Scott, 2005), we tested whether participants had acquired any fragment knowledge (bigrams) of the training sequences, by also using a post-task recognition test of bigrams (see e.g., Johnstone & Shanks, 2001; Perruchet & Pacteau, 1990). Recognition tests mainly assess explicit knowledge, therefore, above chance performance on such tests means that participants may have gained at least some conscious knowledge of particular parts of the grammar.



Figure 1. *Example of a GLOCAL string used in the present experiment*

Method

Participants

An a priori power analysis was used to determine the appropriate sample size. To estimate

the appropriate effect size for the two-way interaction between Group (ASD vs TD) and Level of processing (Global vs Local) we relied on various previous studies. As this is the first known study that investigates local vs global processing in populations with autism vs TD populations with an AGL task, we relied both on previous studies with similar design and populations, but different experimental task (Bouvet et al., 2014 and Ziva & Ziori, 2025) and on the one known study that used exactly the same design, dependent variables and experimental task but different populations, i.e., TD adults (Kiyokawa et al., 2012). The effect sizes of the first two studies range from η_p^2=.11 (the lowest of the two relevant η_p^2 values in Ziva and Ziori, 2025) to η_p^2=.33 (the highest of the three η_p^2 values in Bouvet et al., 2014). In Kiyokawa et al (2012), the effect size was η_p^2=0.19 (as converted from the reported Cohen's d=0.97) in the overall AGL performance and in implicit structural knowledge, and η_p^2=0.32 (as converted from the reported Cohen's d=1.38) in explicit structural knowledge. We opted for the conservative approach of using the lowest of the above effect sizes (i.e., η_p^2=.11, which corresponds to f=.35), to ensure that our study is adequately powered, and more specifically to account for potential overestimation of previous effect sizes, sample variability and methodological differences as well as to increase the generalizability of our findings. The a priori power analysis with an effect size of f=.35 for the interaction of interest, a power level of .90 and an alpha set at .05 indicated a sample size of 24. However, we decided to use a substantially larger sample size (N=42) to handle potential variability due to individual differences, as well as adjust for a potential participant dropout.

Twenty Greek-speaking individuals with autism were recruited from public schools of western Greece. Every participant in the autistic group had received an official diagnosis from public Diagnostic Assessment Centers. Other psychiatric or neurological conditions were used as exclusion criteria. The control group consisted of 22 individuals who had never received any psychiatric or neurodevelopmental disorder diagnosis and was matched with the autistic group in terms of age, $t(40)=1.26$, $p=.214$, $d=.390$, gender, $x^2=.038$, $p=.845$, full-scale IQ, $t(29.09)=-1.71$, $p=.098$, $g=-.532$, verbal IQ, $t(40)=-1.44$, $p=.157$, $d=-.446$, and performance IQ, $t(40)=-1.68$, $p=.094$, $d=-.530$. Both groups underwent an assessment of symptoms indicative of autism, via the Childhood Autism Rating Scale (CARS: Schopler et al., 1986). The above scale is a well-established 15-item screening tool for the identification of autism and the evaluation of the symptoms' severity. The range of scores lies between 15 and 60, with individuals scoring below 30 indicating a non-autistic diagnosis.

Participants' verbal, non-verbal and general intelligence were estimated with the Greek-Cypriot edition (Spanoudis & Tourva, 2012) of the Wechsler Abbreviated Scale of Intelligence (WASI: Wechsler, 1999), which is intended for administration to people over 6 years old. Due to the AGL task's complexity, especially during the test phase, prospective participants with a full-scale IQ below 70 were excluded from this study. This decision aimed at ensuring that all participants from both groups would understand well the instructions and experimental task requirements. The mean age, WASI scores, and CARS scores of our sample are shown in Table 1.

Ethical permission to conduct the experiments was granted from the Greek Ministry of Education, as well as from the Ethical Committee of the University of Ioannina. As part of the ethics protocol of the study, participants' parents gave their informed agreement for their children's participation, by signing a written, informed consent, while all participants (including underage ones) themselves also gave their informed assent before the onset of the study.

Table 1. *Mean age, WASI and CARS scores for the TD and ASD groups*

	Age				WASI scores									CARS scores		
					Full Scale IQ			Verbal IQ			Performance IQ					
	N	M	SD	Range	M	SD	Range	M	SD	Range	M	SD	Range	M	SD	Range
TD	22	13.9	1.9	10.3-17.2	101.3	6.2	87.6-115.3	100.1	8.1	84.2-118.6	102.6	7.7	89.7-121.6	17.0	1.5	15-20.0
ASD	20	14.7	2.1	10.2-17.7	96.5	11.2	74.6-120.7	95.8	11.0	75.4-123.6	97.1	12.5	73.7-128.0	32.8	1.3	30-35.0

Stimuli

For the learning phase, we created grammatical sequences from the two artificial grammars used in Tanaka et al. (2008), with the difference that Roman letters were replaced with Greek ones (Figure 2). The letter sequences were three to six letters long. For half the participants, Grammar 1 was the basis of strings with a global structure, while Grammar 2 produced strings with a local structure; for the other half of participants, the correspondence between grammars and global vs local level was reversed. For the presentation of the GLOCAL sequences, we used blue capital letters on a white background. A large letter displayed on the screen had a height of about 4 cm and a width from 2.5 to 3.5 cm. Participants were presented with a total of 108 training items in a testing screen of 1024 x 768 resolution.

For the test phase, twenty grammatical letter sequences consisting of five to six letters were created from each grammar. Unlike the GLOCAL sequences of the learning phase, these were created using simple letter sequences (i.e., not combinations of larger and smaller letters). Half of the test sequences had been presented during training, while the other half had not. The non-grammatical sequences were constructed by violating the rules in the grammatical sequences, and in particular by replacing one or two characters (see the Appendix in Tanaka et al., 2008). The test phase had 40 pairs of items, such that 20 pairs corresponded to the local items and the other 20 to the global items. For each pair there was a grammatical item and a matched ungrammatical one, with the same length as the grammatical one.

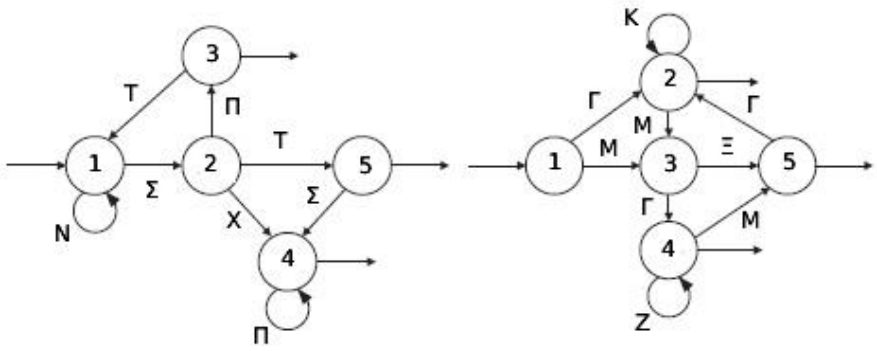


Figure 2. *The two grammars used in the present study (adapted from Tanaka et al., 2008). The one on the left corresponds to Grammar 1, and the other on the right to Grammar 2*

Procedure

All stimuli were presented on a 14-inch laptop screen, with participants sitting at an approximate distance of 50 cm away from the screen. The experimenter maintained a discreet presence only to give the instructions that were necessary to the procedure. This approach ensured that face-to-face contact remained limited and consistent across all participants (cf. Farkas et al., 2023; Farkas et al., 2024).

PsychoPy3 Experiment Builder, v2020.2.8 (Peirce et al., 2019) was used to administer the task. All participants were provided with both oral and written instructions. Examples of the learning and test sequences were presented before proceeding to each of the two phases, and comprehension was tested through follow-up questions asked by the experimenter and feedback during these pre-experimental examples. Special attention was given to individuals with autism by using simple language. Testing took place in quiet rooms,

with the whole session lasting around 40 minutes. All responses were recorded individually for each participant.

During the learning phase, a total of 18 GLOCAL sequences were displayed on the screen. Half the participants saw 18 letter strings following Grammar 1 at one level (e.g., the global) and Grammar 2 at the other (i.e., the local), and the remaining participants saw 18 strings following the reverse correspondence of grammar to levels. Each participant was asked to pay special attention to the strings, without receiving any specific guidance as to which of the two levels to focus on. Each GLOCAL string appeared six times, which produced 108 strings, with each string staying on the screen for 6 sec. Within each block of 18 strings, a message appeared three times in a random order, instructing participants to write down the last sequence of large letters (i.e., the global string) or the last sequence of small letters (i.e., the local string) they had seen. This was done to prevent prolonged distraction. GLOCAL strings were separated from each other by a mask stimulus (a series of "+" signs) that appeared at the location of a string for a 1 sec.

At the end of the training phase, participants heard for the first time that the training strings of each of the two levels had been constructed by some complex rules. Next, they entered the test phase, which comprised two blocks of stimuli, each of which was presented twice. One block contained 20 pairs of sequences generated from the grammar presented at the global level (with each pair consisting of one grammatical and one nongrammatical sequence) and the other block contained 20 pairs of sequences generated from the grammar presented at the local level (with each pair also consisting of one grammatical and one nongrammatical sequence). One sequence in each pair appeared in the upper part of the screen and the other in the lower part of the screen. Thus, during the test phase, participants observed 40 global and 40 local pairs, and for each pair they had to decide which of the two strings was grammatically correct. The matching of grammatical and nongrammatical strings in each pair was randomized for each participant, with each pair always consisting of strings of the same length. The stimulus presentation during testing was counterbalanced among participants, such that half of the participants started with global strings and the other half with local ones. Responding during test was self-paced.

For each response, participants were also instructed to indicate whether their classification stemmed from guessing, intuition, familiarity, recollection or rules (Dienes & Scott, 2005; Scott & Dienes, 2008; see also Ziori & Dienes, 2015; Ziori et al., 2014). More specifically, they were asked to indicate which of the following options best described the basis

of their response:

1. Guess: My judgment is entirely random.
2. Intuition: I feel that my judgment is correct, but I have no idea why.
3. Familiarity: The string seems either familiar or unfamiliar, but I am not able to specify the reasons.
4. Recollection: I remember or fail to remember seeing the exact string or a part of it during training.
5. Rules: My judgment is based on one or more rules that I can report if someone asked me to.

"Guess," "intuition," and "familiarity" options implied an unconscious basis for structural knowledge. By contrast, "recollection" and "rules" responses suggested that structural knowledge might have been consciously accessed, at least in part.

A post-task recognition test was used to evaluate explicit and/or implicit fragment knowledge. Participants were presented with 20 bigrams (i.e., two-letter fragments) corresponding to Grammar 1 and 20 bigrams corresponding to Grammar 2. Half of them had been shown during the learning phase, whereas the other half had not. Participants were asked to discriminate between bigrams that had been presented in the learning phase and those that had not been seen before.

Statistical Analysis

A significance level of .05 was used in all analyses. For the Global-Local AGL task, two-way mixed ANOVAs were conducted to analyze a) overall classification accuracy b) classification accuracy when participants were using implicit structural knowledge and c) classification accuracy when they relied on explicit structural knowledge. Group (TD, ASD) was a between-subjects factor and Level of processing (Global, Local) was a repeated-measures factor. One-sample t tests examined whether general classification accuracy as well as classification accuracy for implicit and explicit attributions was significantly above the level of chance (50%) for each Group and each Level of processing. Independent-sample t-tests were used to compare the mean proportion of implicit and explicit structural knowledge attributions between the two groups.

Regarding the Recognition test, a mixed two-way ANOVA was used to analyze recognition accuracy, with Group (TD, ASD) as a between-subjects factor and Level of processing (Global, Local) as a repeated-measures factor. One-sample t tests assessed whether

recognition exceeded the level of chance (50%) for each Group and each Level of processing.

Correlations were conducted to test whether age, IQ, and autistic symptoms related to participants' classification accuracy.

When we had a large number of comparisons with no pre-specified (a priori) hypotheses, we used multiple comparisons corrections (Benjamini & Hochberg, 1995) to control for the risk of Type I error. By contrast, when hypotheses were set in advance, we did not apply such corrections, as they can inflate the risk of Type II error and potentially obscure important results (see e.g., Glickman et al., 2014; Streiner, 2015; Perneger, 1998).

Although we used null hypothesis significance testing (NHST) as our primary method of analyzing our data, we also estimated Bayes factors (*B*) for the non-significant findings regarding our hypotheses to distinguish between lack of evidence for the alternative hypothesis vs evidence for the null relying on informed priors (e.g., Dienes, 2014). For the interpretation of *B*s, we relied on the following standard convention (Dienes, 2014; Lee & Wagenmakers, 2014): when we test the strength of evidence for the alternative hypothesis (H_1) and we report BF_{10}, *B*s ≥ 3 indicate at least moderate evidence for H_1, whereas *B*s $\leq 1/3$ indicate at least moderate evidence for the null hypothesis (H_0). When we test the strength of evidence for H_0 and we report BF_{01}, *B*s ≥ 3 indicate at least moderate evidence for H_0 and *B*s $\leq 1/3$ indicate at least moderate evidence for H_0. In both cases, *B*s lying between 1/3 and 3 indicate insensitivity to distinguish between H_1 and H_0. When $B_{H(0,6)}$ is reported, it denotes that the Bayesian analyses were performed with half-normal distribution, whereas when $B_{N(0,6)}$ is reported it refers to a normal distribution. In both cases the SD was 6 based on previous relevant research (Ziva & Ziori, 2025; Ziori & Dienes, 2015). The half-normal distribution was used only for a) the directional hypothesis regarding our key interaction, which predicts that, when the task instructions do not direct attention to a specific type of processing, individuals with autism are expected to show a lower global advantage compared to TD individuals and b) testing for learning above chance (which is also directional). For the main effects, we used normal distribution, as no direction can be justified based on the prior literature for the effect of Group and presumably on the opposing responses for the two groups in terms of the Level of processing, which are expected to cancel out the main of effect of the latter factor.

Results

General performance in the Global-Local AGL task

The two-way ANOVA on participants' overall classification accuracy (Figure 3) produced no significant main effect of Group, $F(1, 40)=1.131$, $p=.294$, $\eta_p^2=.028$, $B_{N(0,6)}=0.47$. BF_{10} indicated inconclusive evidence for either H_1 or H_0 regarding the Group effect. The effect of Level of processing was not significant either, $F(1, 40)=.583$, $p=.450$, $\eta_p^2=.014$, $B_{N(0,6)}=3.05$, indicating no difference between Global and Local classification accuracy across the whole sample (note the $BF_{01} > 3$ here provides evidence for H_0). As predicted, the opposing responses expected in the two groups in terms of the Level of processing canceled out the main effect of this factor. Moreover, the analysis revealed no evidence of an interaction between Group and Level of processing, $F(1, 40)= 3.003$, $p=.091$, $\eta_p^2=.070$, $B_{H(0,6)} = 2.80$. The BF_{10} for the interaction indicated insensitive data, and provided only weak evidence for H_1 (i.e., for a greater global over local advantage in the TD group compared to the ASD group), as its value (2.80) suggests that the data are nearly three times more likely under H_1 than under H_0.

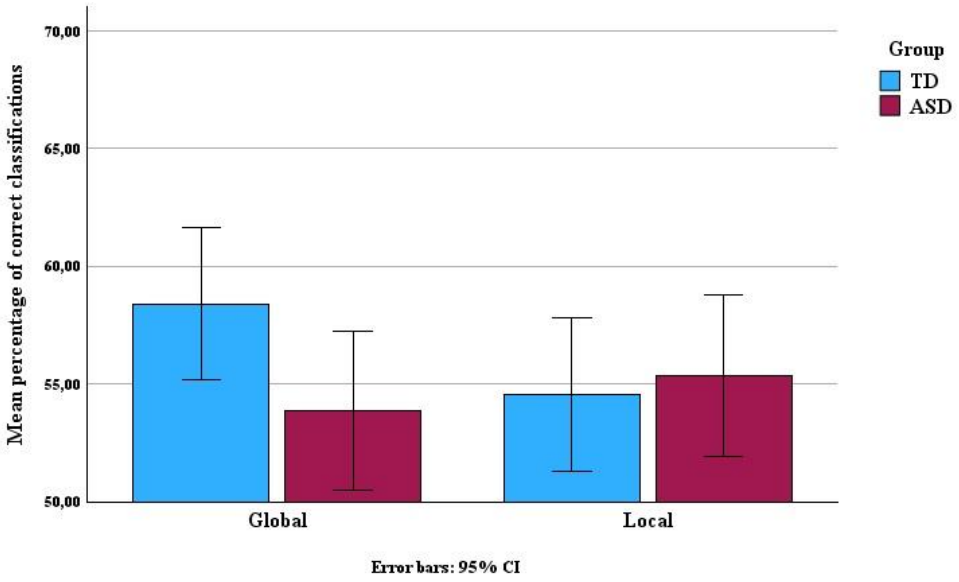


Figure 3. *Overall classification accuracy in the Global-Local task*

One-sample t tests were applied for each group (TD and ASD) and each processing level (Global and Local) to determine whether their overall classification accuracy was significantly above the 50% chance level. For the ASD group, accuracy exceeded chance at

both the global level, *M*=53.88%, SD=7.41 and the local level, *M*=55.38%, SD=8.48. Similarly, for the TD group, at the global processing level, *M*=58.41%, SD=7.54, and the local processing level, *M*=54.55, SD=6.71. Results showed that performance for both groups exceeded a baseline of 50% in both Global and Local processing (all *p*s< .030), indicating some learning from all training stimuli.

Frequency of knowledge attributions

Figure 4 shows how often participants from the two groups used each attribution. No statistically significant differences between the ASD and TD groups were found in terms of the proportions of implicit and explicit attributions they selected for either the global or the local processing level condition or when data from both conditions were combined (all *p*s>.198). We did not apply a multiple comparisons correction in this case, as none of the values were statistically significant in the initial analyses. However, we conducted a 2 × 2 Bayesian ANOVA on the percentage of implicit knowledge attributions. Given that we had no informed priors, we used the default settings of JASP (Version 0.18; JASP Team). The analyses revealed no significant main effects or interaction, all *p*s > .67, BFs > 3.5 (for BF01), providing evidence of no differences in how frequently implicit (and consequently explicit) attributions were used by the participants.

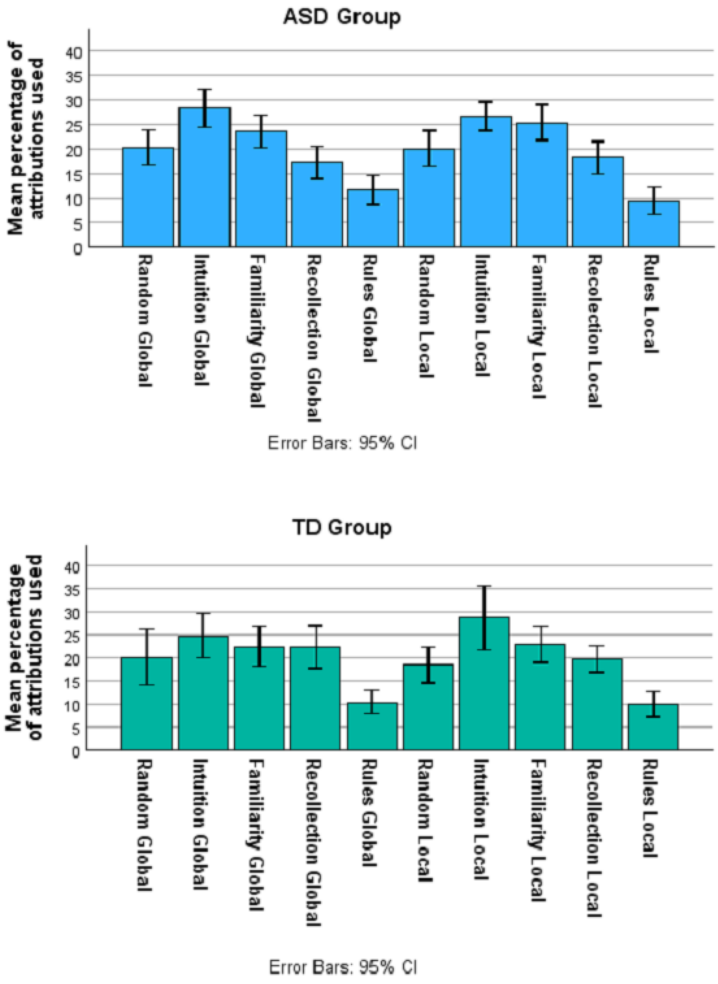


Figure 4. *Mean percentage of the different attributions used by the two groups (ASD vs TD) in each processing level (Global vs Local)*

Accuracy of the different classification attributions

Participants' accuracy for the different types of attributions when classifying the global and the local grammar were used to assess the implicit and explicit structural knowledge and investigate potential differences in the two types of knowledge depending on Group and Level of processing.

When calculating the mean percentage of correct classifications for implicit and explicit knowledge, there may be cases where participants use certain attributions less often than others. For example, some participants might give only a few answers that reflect conscious or unconscious knowledge. In such cases, the result is based on limited observations and could be unrepresentative of their actual knowledge. To address this, we followed Ki-yokawa et al. (2012; see also Guo et al., 2013) and applied a Bayesian adjustment to all

participants that had chosen an attribution at least once, by using the following formula:

$$\text{Proportion correct} = \frac{\text{number of correct responses} + 0.5}{\text{total number of responses} + 1}$$

Following previous studies (e.g., Dienes & Scott, 2005; Kiyokawa et al., 2012), all implicit attributions (random, intuition, and familiarity) were grouped together, and the same was done for explicit attributions (recollection and rules). Grouping the attributions into two broader categories (implicit vs explicit) addresses possible complications arising from the unequal use or low number of certain attributions.

Implicit structural knowledge

The two-way ANOVA on classification accuracy when participants were using implicit structural knowledge yielded no significant main effect of Group, $F(1, 40)=.608$, $p=.440$, $\eta_p^2=.015$, $B_{N(0,6)}=0.38$ (Figure 5). BF_{10} indicated inconclusive evidence for either hypothesis. The effect of Level of processing was not significant either, $F(1, 40)=.441$, $p=.510$, $\eta_p^2=.011$, $B_{N(0,6)}=3.53$ ($BF_{01} > 3$ here provides evidence for H_0). However, the analysis showed a significant two-way interaction, $F(1, 40)= 4.28$, $p=.045$, $\eta_p^2=.097$. More specifically, when using implicit knowledge, the TD group outperformed the ASD group at the Global level, as predicted, $t(40)=-2.08$, $p=.044$, $d=-.642$ ($M=57.60\%$, $SD=7.11$ vs $M=53.29\%$, $SD=6.23$), while regarding differences in performance at the Local level between the two groups, there was data insensitivity, $t(40)=-.64$, $p=.529$, $d=.196$, $B_{H(0,6)}=0.65$ ($M=53.73\%$, $SD=6.70$ for the TD group and $M=55.28\%$, $SD=9.05$ for the ASD group). Paired t-tests were conducted to compare Global and Local classification accuracy for implicit knowledge within each group. Results indicated data insensitivity as to the existence of a difference in Global vs Local processing for the ASD group, $t(19)=-1.04$, $p=.313$, $d=-.232$, $B_{H(0,6)}=0.85$. For the TD group, there was evidence for an advantage of Global over Local processing, $t(21)=1.88$, $p=.074$, $d=.401$, $B_{H(0,6)}=3.03$.

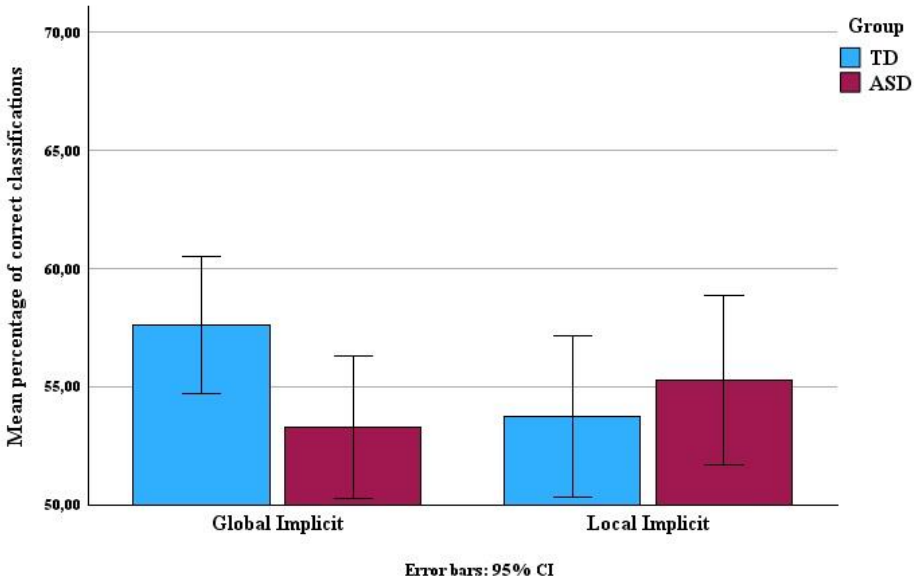


Figure 5. *Participants' mean percentage of correct classifications when using implicit structural knowledge.*

One-sample t-tests showed that when using implicit knowledge, both groups performed significantly above the 50% chance level at both the Global and Local levels of processing (all *p*s<.029). For the ASD group, the means were *M*=53.29%, SD=6.23 at the global level and *M*=55.29%, SD=9.05 at the local level, while for the TD group the corresponding means were *M*=57.60%, SD=7.11 at the global level and *M*=53.73, SD=6.70 at the local level.

Explicit structural knowledge

A two-way ANOVA on participants' classification accuracy when they were using explicit structural knowledge (see Figure 6) showed no significant main effect of Group, $F(1, 40)=3.14$, $p=.084$, $\eta_p^2=.073$, $B_{N(0,6)}=1.39$. BF_{10} indicated inconclusive evidence for distinguishing between H_1 and H_0. The effect of Level of processing was not significant, $F(1, 40)= <.001$, $p=.992$, $\eta_p^2=<.001$, $B_{N(0,6)}=3.16$ (note the $BF_{01} > 3$ here provides evidence for H_0). The two-way interaction, $F(1, 40)=1.87$, $p=.179$, $\eta_p^2=.045$, $B_{H(0,6)}=1.9$ was not significant either, and BF_{10} provided insensitive evidence for distinguishing between the two hypotheses.

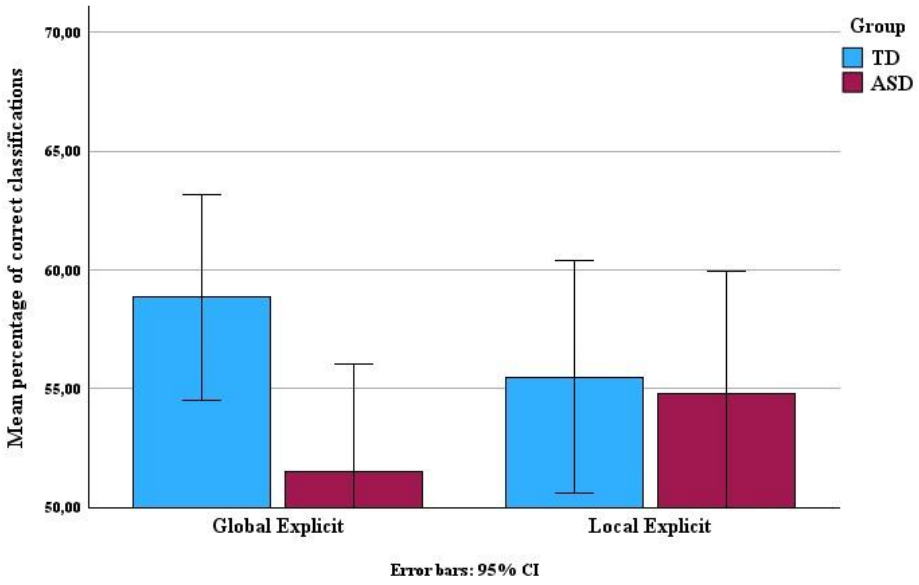


Figure 6. *Mean percentage of correct classifications when using explicit structural knowledge.*

The one-sample t-test that was conducted to examine whether the two groups acquired explicit knowledge (above a chance level of 50%) showed that the ASD group performed significantly above chance at the Local level, $t(19)=2.324$, $p=.031$, $d=.520$ ($M=54.81\%$, SD=9.25), but data were insensitive as to whether their performance at the Global level was close to random, $t(19)=.612$, $p=.548$, $d=.137$, $B_{H(0,6)}=0.65$ ($M=51.51\%$, SD=11.05). By contrast, the TD group performed significantly above chance at the Global level, $t(21)=4.565$, $p=<.001$, $d=.973$ ($M=58.84\%$, SD=9.08) and (nearly) the Local level, $t(21)=1.985$, $p=.060$, $d=.423$, $B_{H(0,6)}=4.08$ ($M=55.50\%$, SD=12.98), with BF_{10} providing evidence for H_I (i.e., above chance performance).

Evaluation of Fragment Knowledge

To investigate whether participants had learned specific parts of the training sequences, both groups completed a bigram recognition test after the main task. Data from nineteen participants with autism were included in the analyses, as one participant in this group failed to complete the test due to fatigue. To assess participants' fragmentary knowledge, we used the mean percentages of correct classifications separately for each group and level of processing. The two-way ANOVA on recognition accuracy yielded no significant main effect of Group, $F(1, 39)=.019$, $p=.890$, $\eta_p^2<.001$, $B_{N(0,6)}=0.76$, with BF_{10}, indicating inconclusive

evidence for distinguishing between H_1 and H_0. The Level of processing was not significant either, $F(1, 39)=.147$, $p=.703$, $\eta_p^2=.004$, $B_{N(0,6)}=5.88$ (the $BF_{01} > 3$ here provides evidence for H_0). Moreover, we found no significant two-way interaction, $F(1, 39)=2.990$, $p=.092$, $\eta_p^2=.071$, $B_{H(0,6)}=2.89$. The BF_{10} for the interaction indicated insensitive data, providing only weak evidence for H_1 (i.e., for a greater global over local advantage in the TD group compared to the ASD group and an at least equal performance of the ASD group in local processing), as its value (2.89) suggests that the data are nearly three times more likely under H_1 than under H_0.

One-sample t tests were applied to examine whether recognition accuracy was significantly above baseline (50%) for each Group and each Level of processing. Results showed that, for the TD group, overall performance was significantly above chance (50%) for both the Global, $t(21)=4.091$, $p=<.001$, $d=.872$ ($M=59.10\%$, SD=10.42) and the Local level of processing, $t(21)=2.085$, $p=.049$, $d=.445$ ($M=55.45\%$, SD=10.22). The ASD group scored above chance at the Local level of processing, $t(18)=2.882$, $p=.005$, $d=.582$ ($M=57.89\%$, SD=11.94), but their performance at the Global level only marginally exceeded chance, $t(18)=1.949$, $p=.067$, $d=.447$, $B_{H(0,6)}=3.75$ ($M=55.00\%$, SD=11.18). However, the value of BF_{10} provided evidence of above chance performance at the Global level as well. Overall, this pattern of findings from the direct recognition test suggests that all participants managed to acquire some fragmentary knowledge of both grammar types.

Correlations

We also searched for possible correlations between participants' overall performance, implicit and explicit learning in both Global and Local conditions, and individual characteristics of participants, and in particular, age, IQ (as measured by WASI) and autistic symptoms severity (as measured by CARS). None of the correlations was statistically significant (all *p*s>.084) after applying the Benjamini-Hochberg method for multiple comparisons correction (Benjamini & Hochberg, 1995), which provides no evidence that the above factors affected the learning outcomes in our sample. Moreover, all BFs provided either evidence for H_0 or inconclusive evidence with respect to H_0 or H_1. The only BF that provided supportive evidence for the existence of a correlation was the BF for the correlation between IQ and explicit performance for only global stimuli and only for the ASD group ($BF_{01}=0.22$).

Discussion

The aim of our study was to investigate how the processing tendencies of children and adolescents with and without autism affects implicit learning. For this purpose, we used an AGL paradigm with two different artificial grammars that incorporated both global and local processing levels. More specifically, the letter strings presented in the learning phase were created by using Navon-type letters, with no specific instructions as to the direction of attention towards the global or local level of stimuli, which allowed us to make inferences about participants' processing tendencies. Given that processing biases may influence the focus of attention, and that perceptual attention affects implicit learning, it was hypothesized that potential differences in processing biases between TD and autistic groups might lead to variations in implicit (and explicit) learning performance, depending on whether individuals focused on global or local structures. More specifically, in alignment with previous theories and research, we predicted that when the task instructions do not direct attention to a particular processing level, people with autism are expected to show a reduced global advantage compared to TD individuals, most probably because of their greater tendency towards local details.

The results from participants' general performance in the AGL task indicate that although the data lean towards the above hypothesis, the evidence supporting the predicted interaction remains inconclusive. The discussion below will unfold possible reasons for the data insensitivity and weak evidence in favour of the hypothesized interaction. The analyses of participants' implicit and explicit structural knowledge revealed an overall similar pattern with some differences, highlighting the importance of using additional measures of consciousness in AGL for revealing more fine-grained details and information about the type of learning and the knowledge acquired.

Implicit learning in autism

This study aims to contribute to a research field with inconsistent findings, that of implicit learning in autism. Our findings align with those of previous work that have provided evidence of preserved implicit learning in young people with autism (e.g., Gidley Larson & Mostofsky, 2008; Gordon & Stark, 2007; Schipul & Just, 2016; Travers et al., 2015) and contrast with others that have reported impairments in implicit learning among individuals with autism (e.g., Gastgeb et al., 2012; Klinger et al., 2007; Mostofsky et al., 2000). They are also consistent with the recent findings of Ziva and Ziori (2025), who found preserved

implicit learning in autism, albeit reduced in comparison to that of a neurotypical group. However, it is not sufficient to ask whether a specific type of learning is preserved in autism or not without attempting to have a deeper understanding of this type of learning.

First, an important step towards a more refined understanding of the type of knowledge acquired in the implicit learning concerns the additional measures that should be utilized to allow for useful distinctions. As stated in the introduction, most of the previous implicit learning studies in autism relied only on participants' performance in the main task or on insensitive measures. This study used sensitive measures of consciousness that have been widely used in implicit learning research, namely a subjective measure of structural knowledge and a recognition test.

It should be noted here that the focus of the present study was on whether participants knew *what* they knew rather than whether they knew *if* they knew when they classified the global and local stimuli; thus, we used participants' attributions to assess the conscious or unconscious structural knowledge that guided their learning when relying on global vs local structural aspects of the stimuli. The recognition test we used also taps into structural knowledge (i.e., knowledge of fragments of the training items). Of course, one may use confidence ratings or even knowledge attributions to draw conclusions about the consciousness of judgment knowledge as well, since correct judgments accompanied by rules, memory, intuition, and familiarity attributions suggest conscious judgment knowledge, whereas correct judgments accompanied by guess attributions suggest unconscious judgment knowledge. However, the distinction between judgment and structural knowledge was beyond the scope of the present work. Future work that is interested in distinguishing between different aspects of consciousness (e.g., access to structural vs judgment knowledge or strategic control) in the implicit and explicit learning of people with autism could combine and compare different methods and/or measures for the assessment of conscious access.

A second step towards a more nuanced understanding of implicit learning is attempting to elucidate different types of processing that might affect the overall implicit learning performance. This was the main aim of the present study by comparing global vs local processing in young people with and without autism.

The role of individual processing biases on implicit and explicit learning

Although prior research reveals inconsistencies with respect to global vs local processing

in ASD vs TD individuals, most studies seem to support a greater global processing advantage in TD individuals compared to autistic individuals which may lead to either a smaller global over local advantage (and perhaps a greater local over global advantage) in people with autism. Importantly, while the vast majority of prior research examined processing biases in autism with tasks such as the Navon task, this study uses the AGL task to fill a gap in literature on implicit learning in autism.

Based on the present findings, the hypothesis predicting a greater global over local processing advantage for the TD group compared to the autistic group (and even a potential local vs global processing advantage for individuals with autism) received inconclusive evidence in terms of our participants' overall AGL performance, as well as in terms of their explicit structural knowledge, as indicated by Bayes factors. In terms of implicit structural knowledge, the predicted interaction was confirmed in that the TD group demonstrated a global over local processing precedence. In addition, the TD group outperformed the autistic group in global processing, whereas with respect to the local over global processing bias in the autistic group as well as with respect to the comparison of the two groups in local processing the data were insensitive. Importantly, both groups showed implicit knowledge at an above chance level, suggesting that all participants, independent of group, were able to extract implicit structural information from both artificial grammars. Thus, participants with autism could engage in implicit learning regardless of the level of processing. This is in agreement with Kourkoulou et al. (2012), who found that participants with autism could implicitly extract patterns from local and non-local contexts, while performing a contextual cueing task.

In general, our findings regarding information processing in autism align with previous research, particularly with the work of Van der Hallen et al. (2015) and Van Eylen et al. (2018), who reported that individuals with autism do not exhibit severe difficulties in holistic processing (see also Muth et al., 2014). The current global advantage of the TD group compared to the autistic group in the acquired implicit structural knowledge does not imply a deficit in the global processing of participants with autism. Presumably, a local processing bias in participants with autism might have weakened the degree and/or the quality of global processing but not to a detrimental degree, as it remained above a chance level in terms of the overall accuracy and the implicit knowledge acquired. The above interpretation is in line with Mottron et al. (2006) who argue against a global processing deficit in autism; instead, individuals with autism may engage in holistic processing less frequently compared

to TD individuals, giving priority to a local processing mode. If individuals with autism treat global processing as an unfavoured type of processing, this could mean that in a task that allows processing at both local and global levels, such as in the present AGL task, they may have relied primarily on local processing, using global processing only as a secondary processing mode. Meanwhile, the TD group's greater implicit knowledge at the global level, together with a comparable performance at the local level, indicates more flexible processing that allows them to switch between local and global processing as required.

This possible flexibility for the TD group coincides also with their above chance explicit knowledge at both processing levels. For the autistic group, the overall pattern of explicit knowledge results suggests less robust knowledge at the global level of processing, but evidence regarding this level of processing remains inconclusive, so no firm conclusions may be drawn about that.

A trend towards an interaction pointing to a greater global processing advantage in the TD group compared to the autistic group was also found in the recognition test which evaluated participants' fragment knowledge, namely knowledge of the structural details (i.e., pairs of letters that make up the artificial grammars) that were learned during the learning phase. The results showed that such fragmentary knowledge, which is to a large extent considered explicit, exceeded a chance level for both groups in both types of grammar (i.e., global and local). Presumably, the quality of fragmentary knowledge for smaller fragments was higher than that of larger ones, which allowed the development of sufficient conscious knowledge, independent of level of processing (see Cleeremans and Jiménez's, 2002 theory of consciousness, according to which high quality knowledge gives rise to conscious knowledge).

The insensitivity of our data with respect to a reduced global over local advantage in the autistic group vs the TD group in the overall AGL performance (as well as in their implicit and explicit knowledge separately) leaves the question of the existence of different processing types in the two groups open. Several reasons might explain this inconclusive evidence regarding our predicted interaction between Group and Level of processing in the present study, despite the use of a robust design with a sample size that is much larger than the one indicated by the a priori power analysis. The observed variance in our sample, most probably due to the complexity of the task and the individual differences in the strategies possibly applied by both groups (especially for the group with autism and especially for the putative most challenging for them global processing condition) to manage the increased

task demands, is likely to have weakened the strength of the interaction. Indeed, the current AGL task with two grammars is a demanding task that might have caused occasional fatigue or loss of focus or might have resulted in performance instability (e.g., frequent change of strategies or modes of processing) for the present sample, all of which may be possible reasons of noise in the data.

Another possibility of why the data showed a trend towards an interaction but remained insensitive is because the true effect size of the interaction might be smaller than the one hypothesized in the a priori analysis.

All the above do not indicate absence of an effect but possible reasons for the attenuation of an effect with potential theoretical significance that is worth exploring further. It is also worth noting here that the null main effect of Level of processing we found in all analyses is consistent with an interaction, as the reversed pattern of responses from the two groups in the two different grammars explains the way the above main effect cancels out overall.

A methodological detail that might have also affected the strength of the processing tendency of the two groups towards global vs local aspects is the occasional reproduction of the global and local letter sequences that our instructions demanded. One might argue that this instruction might have introduced some sort of bias towards both grammars (even if indirectly). However, this possibility seems unlikely as participants had to reproduce only a minimal number of sequences (18 out of the 108 training strings). The above instruction was given to bring the two grammars to participants' attention and thus render both of them task-relevant, as task relevance has been shown to enhance implicit learning in AGL (see Eitam et al., 2009). This procedure allows us to test whether the two different groups learn only one or both sequence types, when these are of equal task relevance or whether their processing tendencies are strong enough to impede or favor the learning of a certain sequence type. Moreover, the reproduction of grammar sequences served as a means of decreasing the possibility that the particular sample (young people, especially young individuals with autism) would demonstrate insufficient visual attention to the on-screen stimuli, which would be detrimental for performance in an AGL task.

This study builds upon and extends the work of Ziva and Ziori (2025), by providing a more in-depth exploration of the role of processing style on implicit learning. While Ziva and Ziori found evidence of implicit knowledge in participants with autism, such participants in their study exhibited a global processing advantage and reduced local processing

efficiency, leading the authors to presume that local processing difficulties may have contributed to the reduced implicit knowledge of their autistic group compared to that of TD participants. However, such a relationship is not supported by the findings of the current study.

As already mentioned, Ziva and Ziori examined implicit learning and perception style in individuals with autism using two separate tasks, an AGL task that assessed implicit learning and a Navon task that measured participants' global-local processing style. First, in the Navon task used by Ziva and Ziori, participants were given explicit instructions to direct their attention to either global or local stimuli. It is possible that this approach has influenced participants' performance, leading to outcomes that reflect the imposed task demands rather than natural processing tendencies. This interpretation aligns with research showing that in selective attention tasks, where participants are directed to focus on a specific level, individuals with autism may adopt different processing strategies that restrict their typical processing biases, whereas, divided attention tasks, such as the one used in our study, tend to favor the individual's dominant processing style (see e.g., Koldewyn et al., 2013; Plaisted et al., 1999). Furthermore, the use of two distinct tasks in Ziva and Ziori's study does not clearly uncover the actual relationship between implicit learning and processing style.

Moreover, the ASD group in Ziva and Ziori's study included subjects with mild to severe ASD symptoms and a mean full-scale IQ of 67.5. Since the local processing difficulties reported by Ziva and Ziori are not a typical phenomenon in autism, it is possible that lower cognitive abilities of their sample contribute to challenges in task performance in general, irrespective of characteristics specific to autism. This interpretation agrees with Van Eylen et al. (2018), who observed that individuals with autism with higher IQs tend to exhibit stronger information processing skills (for a similar finding in a TD group, see Dore et al., 2018). The present study adopted an ASD sample better matched to TD controls, in an effort to minimize the possibility that differences in intellectual ability confuse our results.

The role of age, IQ and ASD symptoms severity on learning outcomes

In this study, we also explored whether other individual characteristics, such as age, intellectual ability, and ASD symptoms severity were associated with overall, implicit, and explicit learning performance in the two processing conditions. Overall, we found no evidence that the above factors correlated significantly with performance on the AGL task or with

implicit and explicit learning, suggesting that the observed differences in implicit learning performance between participants with autism and TD participants cannot be attributed to these particular characteristics. Similarly, previous studies with autistic groups (e.g., Brown et al., 2010; Gordon & Stark, 2007; Travers et al., 2010; Travers et al., 2013; Xie et al., 2024; Ziva & Ziori, 2025; but see Gastgeb et al., 2012; Schipul & Just, 2016; Travers et al., 2015) found no relationship between implicit learning and such factors. The only evidence for a correlation we found was between IQ and explicit global processing and only for participants with autism, a finding that coincides with the fact that conscious processing of global information was the most cognitively demanding processing type for this group. Of course, in our study the two groups were age- and IQ-matched. Moreover, our autistic group included individuals who exhibited mild or mild-to-moderate symptoms of the disorder. Therefore, further research with more diverse samples may help determine whether these findings generalize to individuals with autism who have more intense symptoms and a wider range of cognitive abilities.

In conclusion, our study offers new insights into the effect of individual characteristics in implicit learning in general and in autism in particular, by showing how different processing biases may influence performance. Most previous work in the field has overlooked individual processing biases, focusing instead on the role of more pronounced autistic characteristics or on simple group comparisons on performance. Our findings highlight the possibility that the processing level at which regularities are presented in an implicit learning task may have a moderating effect in implicit learning performance in both typical populations and populations with autism, particularly in tasks where global or local processing is important for task success. In this sense, we suggest that a simple intact vs impaired description for implicit learning in autism is inadequate, and that implicit learning performance in autism could be better understood as context-dependent, since it is possible that specific individual characteristics, such as processing biases, may be contributing factors that shape implicit learning outcomes in such groups. Clearly, the findings of the present study cannot account for all inconsistencies in this research field, given that implicit learning outcomes may be affected by many confounding variables, such as sample characteristics, participants' strategies and/or specific task features. Nevertheless, our results add to the ongoing research by emphasizing the need to further explore the role of processing tendencies in implicit learning in autism, and particularly the task conditions under which implicit learning is more likely to pose challenges for such individuals. More specifically,

our findings provide suggestive evidence of an interesting trend that is worth exploring further: if an implicit learning task combines both global and local processing and does not direct attention to either of the two, then people with autism will most likely achieve an adequate local performance (if not better than TD people) and might be less effective in global processing, without implying a global processing deficit. This perspective provides a potential basis for understanding the contrasting findings across implicit learning studies and may guide future research particularly interested in the relationship between implicit learning and individual characteristics in general and in the degree to which any potential differences in the learning of populations with autism and TD populations might stem from different processing biases (i.e., a tendency towards holistic vs more detailed processing) in the two populations.

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Chapter 4

Study 3

Implicit learning of social vs non-social information in autism

This chapter has been submitted as:

Ziva, A. & Ziori, E. (under review). Implicit learning of social vs non-social information in autism.

Abstract

Implicit learning is a core mechanism underlying the acquisition and processing of social information in both typical and atypical development. Despite its importance, relatively little is known about the implicit learning of social information in autism. The present study examined the implicit (and explicit) learning of social (faces) versus non-social (colours) stimuli in 21 young individuals with high-functioning autism and 23 typically developing (TD) controls using a modified Artificial Grammar Learning (AGL) paradigm. Participants observed sequences of coloured male faces in which facial identities and colours followed different grammatical structures. Compared to TD participants, individuals with Autism Spectrum Disorder (ASD) showed reduced overall performance for faces, whereas performance for colours was comparable between the two groups. Analyses of knowledge awareness showed no significant between-group differences in implicit knowledge for either stimulus type. However, within the ASD group, implicit knowledge of faces was significantly lower than that of colours, whereas TD participants demonstrated comparable implicit learning across stimulus types. By contrast, explicit knowledge differed between groups only for faces, with the ASD group showing significantly poorer performance than the TD group. Overall, these findings underline the importance of considering stimulus type when evaluating learning mechanisms in autism and suggest that social information poses specific challenges for autistic people, despite their largely preserved implicit learning abilities.

Keywords

implicit learning, artificial grammar learning, social vs non-social, autism

Implicit learning of social vs non-social information in autism

Implicit learning is a fundamental cognitive ability that has been shown to support the development of language acquisition (Conway & Pisoni, 2008; Saffran et al., 1996), social and communicative abilities (Ivanchei et al., 2019; Lieberman, 2000), and motor skills (e.g., Karin & Nordin-Bates, 2020; Van der Kamp et al., 2015). This type of learning commonly occurs through exposure to repeated experiences in the absence of explicit instruction and allows people to detect patterns and learn rules unintentionally and without conscious awareness (e.g., Reber, 1967; see Ziori, 2023 for a review). The artificial grammar learning (AGL) task, introduced by Reber (1967), has been widely used for studying implicit learning (see e.g., Jurchiș et al., 2020; Kiyokawa et al., 2012; Mealor & Dienes, 2013; Pothos, 2007; Ziori & Pothos, 2015). In this task, individuals first observe strings of symbols (e.g., letters or shapes) that, unbeknownst to them, are created based on complex structural rules. In a test phase that follows they are shown novel strings and have to decide whether each one follows the same rules as those governing the training examples. Importantly, people are typically able to distinguish between strings that obey and strings that violate the rules more often than expected by pure guessing; however, their ability to report what they have learnt is usually limited, suggesting that much of this knowledge remains outside conscious awareness. A common observation, however, is that test-phase performance tends to draw on both implicit and explicit forms of learning, suggesting that these processes may operate together to support performance (e.g., Dienes & Scott; 2005; Shanks & John, 1994; Sun et al., 2007).

Social cognition and behavior are highly dependent on implicit learning mechanisms (e.g., Frith & Frith, 2012; Heerey & Velani, 2010; Ivanchei et al., 2019; Jurchiș & Dienes, 2023; Lieberman, 2000; Norman & Price, 2012). In everyday life, people engage in social situations and gradually form patterns from socially meaningful information including eye gaze direction, gestures, facial expressions, physical movements or prosody. This process primarily occurs without conscious effort and supports the development of social functioning by allowing individuals to automatically interpret socially relevant signals, understand others' emotions or intentions and respond appropriately in different situations. Evidence from implicit learning research also suggests that social stimuli, especially faces, may naturally attract attention because of their social importance, making them more likely to be processed and learned implicitly. Using an AGL paradigm, Eitam et al. (2014) found that

TD individuals showed some implicit learning for task-irrelevant faces, but not for task-irrelevant non-social stimuli, such as colours or buildings. These findings suggest that, in typical development, implicit learning mechanisms may place greater emphasis on social compared to neutral information. Consequently, and consistent with the authors' suggestion, a reduced attention to -or interest in- social stimuli under implicit learning conditions may partly account for the social difficulties commonly observed in populations such as people with autism.

Several studies on social cognition have shown that in typical development, individuals are naturally predisposed from early in life to attend to and learn from socially meaningful information (e.g., Gluckman & Johnson, 2013; Johnson et al., 1991; Meltzoff, 2007). By contrast, a lower social interest has been detected in several clinical conditions, with Autism Spectrum Disorder (ASD) being the most representative case. Autism is a complex neuro-developmental state that persists across the lifespan and is typically associated with difficulties in the domains of communication and social functioning (APA, 2013). In this paper, we refer to autism adopting both person-first (e.g., group with autism) and identity-first (e.g., autistic group) language. This approach is in line with recommendations from recent research and aims to reflect the range of preferences expressed by both autistic individuals and professionals (e.g., Buijsman et al., 2023; Martinez et al., 2025).

One of the most influential accounts proposed to explain atypical social processing in autism is the social motivation hypothesis (Chevallier et al., 2012), which suggests that, relative to typical development, autism is characterized by individuals' lower interest to engage with social material during social orienting, social maintaining, and social reward processes. However, a systematic review of relative studies pointed to mixed evidence, and thus insufficient to provide strong support for this account (Bottini, 2018).

An alternative view proposes that weaker social attention in autistic individuals (compared to TD controls) reflects a relative bias towards non-social stimuli, particularly those related to restricted interests such as vehicles and geometric shapes (Sasson & Touchstone, 2014). However, subsequent findings have not consistently supported this explanation, suggesting that reduced social attention in autism does not necessarily reflect enhanced processing of restricted-interest stimuli (e.g., Ambarchi et al., 2023; Harrison & Slane, 2020).

Although findings vary across paradigms and stimulus types, a relative disadvantage associated with autism in relation to social information appears to be a robust finding, with

autistic individuals consistently showing less efficient processing of social stimuli compared to TD individuals. For example, Vacas et al. (2021) found reduced social attention in autism using an eye-tracking visual preference task involving emotional faces paired with non-social objects. Although both groups showed similar patterns of visual attention, autistic children spent less time attending to faces compared with TD children, indicating reduced engagement with socially relevant stimuli. In another study, Congiu et al. (2024) used visual orienting and preferential looking tasks involving faces and non-social stimuli. They found that TD preschoolers showed a robust bias toward faces, whereas their autistic peers were less likely to orient first toward faces and spent less time attending to them across the viewing period. Similar findings have been reported across a range of paradigms, consistently showing a social disadvantage in autistic individuals relative to TD people (e.g., Ambarchi et al., 2023; Chawarska et al., 2013; Gale et al., 2019; Harrison & Slane, 2020; Stavropoulos & Carver, 2014; Todd & Bahrick, 2023).

The above processing difficulties in autism are restricted to social information. With respect to the processing of -and, in particular, with respect to visual attention to- non-social stimuli, a recent meta-analysis by Hinz et al. (2024) found no overall differences between autistic and non-autistic children.

Presumably, the atypical patterns of social processing in autism could be better understood within the domain of implicit learning. As already mentioned, the development of social skills largely emerges through implicit learning processes. In autism, weaker attention to social stimuli may limit opportunities to implicitly acquire socially relevant patterns, while implicit learning of non-social patterns may remain relatively unaffected.

Accumulating evidence suggests that implicit learning in ASD remains unharmed or relatively preserved across a variety of well-established implicit learning paradigms, including the AGL task (e.g., Brown et al., 2010; Costea, 2018; Ziva & Ziori, 2025; Ziva et al., 2026; but see Klinger et al., 2007), the serial reaction time (SRT) task (e.g., Barnes et al., 2008; Brown et al., 2010; Müller et al. 2004; Nagy et al., 2025; Németh et al., 2010; Pesthy et al., 2023; Treves et al., 2024; but see Hoof et al., 2025; Mostofsky et al., 2000), and the contextual cueing (CC) task (e.g., Barnes et al., 2008; Brown et al., 2010; Kourkoulou et al., 2012; but see Xie et al., 2024). Nevertheless, despite this extensive literature, little is known about implicit learning of social vs non-social input in autism.

In an early work by Scott-Van Zeeland et al. (2010), autistic and TD children completed two versions of a feedback-based reinforcement learning paradigm combined with fMRI,

in which they learned stimulus–outcome associations under both social (smiling/sad faces) and non-social (monetary) conditions, without explicit instruction. Their findings showed that TD children successfully learned in both conditions and showed strong activation in reward-related brain areas, particularly in response to social rewards. By contrast, children with autism showed reduced implicit learning overall and diminished neural responses to both reward types, especially in the social condition compared to TD children, suggesting a lower responsiveness to social reward. The study by Scott-Van Zeeland et al. (2010) is perhaps the only study to date that has examined implicit learning in autism by comparing social and non-social contexts within the same experimental task. However, it should be noted that the task used in the above study lacks the purely passive conditions of the highly representative implicit learning paradigms like the AGL and SRT, as it involved reward-based learning of relatively simple associations with trial-by trial feedback, which also makes it difficult to distinguish between learning and reward-related processing.

Other studies have provided important insights into implicit learning of socially meaningful material in autism, albeit without including a non-social comparison condition. For example, Hudson et al. (2012) used a gaze-based implicit learning paradigm in which faces were linked to "friendly" or "unfriendly" patterns through their gaze and expressions. In a subsequent gaze-cueing task which assessed how participants' attention followed the faces' gaze, it was found that individuals with lower autistic traits showed clear implicit learning, whereas individuals with higher autistic traits showed little or no such modulation, indicating reduced sensitivity to socially meaningful information acquired implicitly. Similarly, an AGL study using facial emotional expressions (Costea, 2018) provided evidence of implicit learning of socially meaningful structures, albeit with a small negative association between autistic traits and performance. This finding implies that implicit learning of social information may be largely preserved in autism but may be attenuated as autistic traits increase. Another implicit learning study using social stimuli (child photographs) in a CC paradigm (Xie et al., 2024) found that implicit learning of socially relevant cues in autistic children was similar to that of their TD peers when learning relied on a single cue source; however, when social (identity) cues were integrated with additional (spatial) contextual cues, implicit learning was observed only in TD individuals, suggesting that implicit processing of social information in autism may become less efficient when multiple contextual sources must be integrated simultaneously. Finally, in a very recent study (Hoof et al., 2025) with a modified SRT task involving sequences of social interactions between characters, adults

with autism showed weak implicit learning abilities compared to TD adults who showed clear implicit social sequence learning.

In all, research findings suggest that implicit learning per se is not fundamentally impaired in autism, but it appears less robust compared to TD individuals when social information is involved. However, unlike the broader literature, which generally suggests a disadvantage for social compared to non-social stimuli only in autistic individuals and not in TD individuals (who might even demonstrate a social processing advantage), the existing implicit learning literature is constrained by a shortage of implicit learning studies directly investigating the competition between socially relevant and socially irrelevant information in people with and without autism. Thus, it remains unclear whether implicit learning mechanisms in autistic individuals differentially prioritize social vs non-social material compared to neurotypical controls, and to what extent the observed differences reflect biases towards social or non-social information, or broader processing and learning differences between groups.

The present study addresses this gap by directly comparing implicit learning of social (human-related) versus non-social (non-human) information within the same AGL paradigm. Specifically, faces (social stimuli) and colours (non-social stimuli) are embedded within the same stimulus sequences, presented as coloured male faces, with each type of information following a different underlying grammar (Figure 1). Importantly, the use of coloured faces in this study eliminates potential attentional confounds (see, e.g., Eitam et al., 2014), as both social (faces) and non-social (colours) features are fully integrated within the same visual stimulus. In addition, participants received no specific instructions regarding the direction of attention to either feature. This design therefore allows us to examine how attention is allocated between non-social and social cues, and whether one type of information is preferentially learned when both are simultaneously available.

This study also examines the (un)conscious status of the acquired knowledge by using sensitive subjective measures of awareness. In particular, we employ a method introduced by Dienes and Scott (2005) and widely used in AGL research, which discriminates between implicit and explicit structural knowledge by asking participants to report the basis of their classification decisions. Notably, only a few implicit learning studies with autistic groups have used such measures (Costea, 2018; Ziva & Ziori, 2025; Ziva et al., 2026); instead, relative studies have relied primarily on task performance (e.g., Klinger et al., 2007;

Mostofsky et al., 2000; Müller et al., 2004) or on awareness measures that have been criticized for their limited sensitivity, such as verbal reports (e.g., Brown et al., 2010; Pesthy et al., 2023; Roser et al., 2015) and recognition or prediction measures (e.g., Kourkoulou et al., 2012; Travers et al., 2010; Treves et al., 2024; Xie et al., 2024).



Figure 1. *Example of a sequence of coloured faces used in the present task.*

Method

Participants

Given the lack of previous research matching the combination of the present experimental task, design and specific sample, we could not rely on a prior effect size for the interaction of interest in an a-priori power analysis. Therefore, in our a-priori power analysis, we assumed a standard medium effect size of f=.25, power was set at .80 and alpha at .05, which yielded a minimum sample size of N=34. However, to account for potential data exclusion, we increased the sample size to N=44. The total of 44 Greek-speaking adolescents and young adults participating in the study included 21 individuals with autism (15 male) and 23 TD controls (17 male). Individuals in the target group were formally diagnosed with ASD by public Diagnostic Assessment Centers. Individuals with additional neurological or psychiatric disorders were excluded. The TD participants had no history of neurodevelopmental or other clinical diagnosis. The two groups were matched for age, $t(42)=1.092$, $p=.281$, $d=.330$, gender, $x^2=.030$, $p=.862$, full-scale IQ, $t(42)=-1.101$, $p=.277$, $d=-.332$, verbal IQ, $t(42)=-.484$, $p=.631$, $d=-.146$, and performance IQ, $t(42)=-1.315$, $p=.196$, $d=-.397$. All participants were assessed for autism-related characteristics using the Childhood Autism Rating Scale (CARS; Schopler et al., 1986), a widely used 15-item measure of ASD symptoms presence and severity, with scores ranging from 15 to 60 (and scores below 30 indicating non-autistic functioning). Intellectual abilities were assessed with the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999) in its Greek-Cypriot adaptation (Spanoudis & Tourva, 2012), suitable for individuals aged 6 years and above. Descriptive statistics for age, IQ, and CARS scores are presented in Table 1.

The study received approval by the Ethics Committee of the University of Ioannina. Informed written consent was obtained from parents or legal guardians, and all participants provided their assent before taking part.

Table 1. *Mean age, intellectual functioning, and autism symptoms scores of the two groups*

	Age				WASI scores									CARS scores		
					Full Scale IQ			Verbal IQ			Performance IQ					
	N	M	SD	Range	M	SD	Range	M	SD	Range	M	SD	Range	M	SD	Range
TD	23	15.8	1.4	13.2-18.6	102.6	10.2	87.5-122.8	101.8	10.5	83.7-125.8	103.4	13.1	85.2-130.4	17.5	1.8	15-21.0
ASD	21	16.4	2.1	13.4-19.8	99.2	10.3	84.5-121.6	100.1	11.6	78.8-123.8	98.2	12.9	81.0-134.3	32.8	1.5	30-35.0

Stimuli

During the learning phase, participants observed sequences of coloured male faces with neutral expressions, generated using AI. Each sequence was 3–6 items long and followed the rules of the two grammars applied in Tanaka et al. (2008), one determining the order of faces and the other the order of colours (Figure 2), with this mapping counterbalanced across participants. Stimuli were presented on a screen with a white background and a resolution of 1024 x 768 pixels.

In the test phase, participants viewed 20 pairs of face sequences and 20 pairs of colour sequences. In the Face condition, sequences were presented using faces without colour variation, whereas in the Colour condition, sequences were presented using colours without faces, allowing each type of information to be tested independently. Each pair included one grammatical and one ungrammatical sequence of equal length (5–6 elements). Half of the grammatical sequences had appeared in the learning phase, and the others were novel. Ungrammatical sequences were created by violating the underlying grammar rules, typically by altering one or two elements.

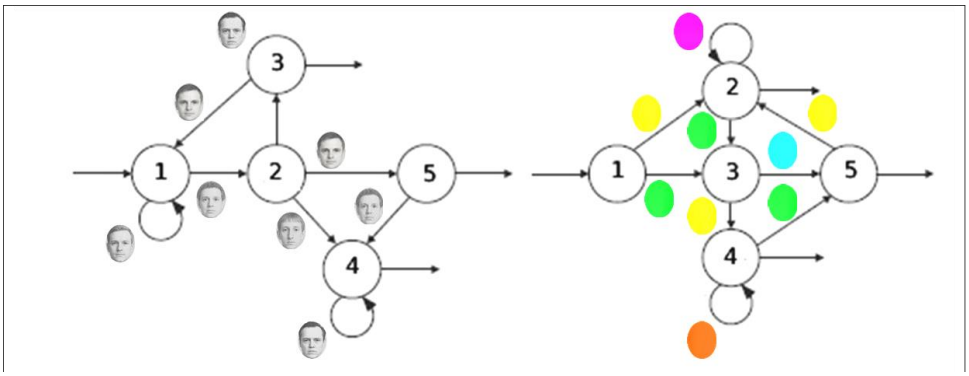


Figure 2. *The grammars employed to generate the stimuli (adapted from Tanaka et al., 2008). Grammar 1 is shown in the left and Grammar 2 in the right.*

Procedure

The experiment was administered using PsychoPy software (v2024.2.4; Peirce et al., 2019). Participants were given written and verbal instructions prior to the task. Before each phase (learning and test), example sequences were presented, and participants' understanding was checked through follow-up questions and feedback. Instructions were adapted using simple language so as to be easy to follow, particularly for participants with autism. The task was conducted in quiet rooms for a total testing time of approximately 30 minutes. Participants were seated about 50 cm away from a 15.6-inch laptop screen on which all stimuli were presented. The experimenter remained present to provide necessary instructions, ensuring minimal and consistent face-to-face interaction in the entire sample (cf. Farkas et al., 2024). Participants were tested individually.

During training, a set of 18 different sequences of coloured faces were presented, each repeated six times, resulting in 108 training trials shown in a random order. The sequences followed two artificial grammars, one controlling the order of faces and the other controlling the order of colours. For half of the participants, Grammar 1 determined the sequence of faces and Grammar 2 the sequence of colours, while for the remaining participants the reversed mapping was applied. Participants were instructed to attend carefully to the stimuli, without being told that any underlying rules existed or which aspect of the stimuli (faces or colours) to focus on. Each sequence was displayed for 6 seconds and was followed by a brief mask (a row of "+" symbols) presented for 1 second at the same screen location. To maximize participants' attention to the stimuli, attention checks were included (cf. Eitam et al., 2014; Eitam et al., 2009). At random intervals during the learning phase, a sequence appeared and participants had to decide whether it was identical or different from the one

they had just seen, by pressing the corresponding "yes" or "no" key. This procedure was repeated 18 times, each time using a different sequence from the 18 sequences created for the learning phase.

At the end of the learning phase, participants were told that the sequences they had viewed followed some complex rules. They then proceeded to the test phase, which consisted of two blocks, one assessing knowledge of face sequences and the other assessing knowledge of colour sequences. Each block included 20 pairs of sequences, each of which contained one grammatical and one ungrammatical sequence of equal length. In the Face condition, sequences were presented using faces without colour variation, whereas in the Colour condition, sequences were presented using only the colours. Within each pair, one sequence appeared below the other on the screen. Participants were instructed to select the sequence they believed followed the rules learned during training. Each block was presented twice so participants had to provide an answer for a total of 80 pairs of sequences (40 pairs of faces and 40 pairs of colours). To control for order effects, half of the participants viewed the face sequences first and the colour sequences second, while the other half viewed the two sequence types in the reverse order. All responses during the test phase were self-paced.

After each decision in the test phase, participants were asked to indicate the basis of this decision, following the procedure developed by Dienes and Scott (2005; see also Norman & Price, 2012; Scott & Dienes, 2008; Ziori et al., 2014). Specifically, they selected one of the following categories that best described how they made their judgment:

Guess: at random, with no perceived basis for the choice

Intuition+Familiarity: because the sequence felt correct or familiar (or the other one felt incorrect or unfamiliar) without knowing why.

Recollection: because I remember having seen (or not seen) the sequence during the learning phase

Rules: because I applied one or more rules that I could describe.

Given that intuition and familiarity are two closely related subjective experiences we combined them into a single option to reduce task complexity for this sample. Responses attributed to guessing and intuition+familiarity were taken to reflect unconscious (implicit) knowledge, whereas responses believed to rely on recollection and rules were considered to indicate at least some degree of conscious (explicit) knowledge of the grammar structure.

Statistical Analyses

To examine general performance on the AGL task, a two-way mixed ANOVA was performed for overall classification accuracy, whereas to examine the unconscious and conscious status of the acquired structural knowledge two-way mixed ANOVAs were performed separately for (a) the accuracy of responses attributed to implicit knowledge, and (b) the accuracy of responses attributed to explicit knowledge, respectively. In these analyses, Group (TD vs. ASD) served as the between-subjects factor, whereas Stimulus Type (Faces vs. Colours) was treated as a within-subjects factor. The significance level was set to .05 in all statistical analyses.

To determine whether performance exceeded a chance level, one-sample t-tests compared overall AGL classification accuracy, and accuracy of implicit and explicit decision attributions against 50% separately for each Group and Stimulus Type. Group differences in accuracy were assessed using independent-samples t-tests, whereas paired t-tests were used to assess stimulus-type differences within each group. In addition, correlational analyses explored potential associations between classification performance and participants' age, IQ, and autistic symptomatology.

A limitation of conventional null hypothesis significance testing is that a non-significant *p*-value does not indicate whether there is genuinely no effect or whether the data are simply not sensitive enough to detect one. To address this, we calculated Bayes factors (*B*) for the non-significant results of all our main analyses, which allow for a more informative interpretation of non-significant findings. The calculations were based on an informed prior using a standard deviation (SD) of 6, derived from previous studies using similar tasks (Ziori & Dienes, 2015) and both similar tasks and samples (Ziva & Ziori, 2025; Ziva et al., 2026). Following the recommendations of Dienes (2014) and Lee and Wagenmakers (2014), Bayes factors of 3 or above were interpreted as evidence for the alternative hypothesis (H_1), values of 1/3 or lower as evidence for the null hypothesis (H_0), and values between 1/3 and 3 as indicating inconclusive evidence to distinguish between the two hypotheses.

Where analyses involved multiple exploratory comparisons without specific a priori predictions, the Benjamini & Hochberg (1995) procedure was applied to reduce the probability of Type I error. By contrast, planned analyses based on predefined hypotheses were not corrected for multiple comparisons, given concerns that overly conservative corrections may increase Type II error rates and mask theoretically meaningful effects (e.g., Glickman et al., 2014; Streiner, 2015).

Results

Overall AGL accuracy

A 2 x 2 mixed ANOVA examining mean classification accuracy showed no significant between-group differences, $F(1, 42)=.836$, $p=.366$, $\eta_p^2=.020$, $B_{N(0,6)}=.447$ (the $BF_{10}=.447$ is equivalent to $BF_{01}=2.237$, indicating inconclusive evidence for a null difference between the two groups). However, a significant main effect of Stimulus Type emerged, $F(1, 42)=35.231$, $p<.001$, $\eta_p^2=.456$, indicating superior general classification accuracy for Colours compared to Faces (M=64.49%, SD=7.58 vs M=56.76%, SD=8.29), independently of Group.The above main effect was conditional upon a significant Group by Stimulus Type interaction, $F(1, 42)=7.551$, $p=.009$, $\eta_p^2=.152$. As shown in Figure 3, the TD group outperformed the ASD group while classifying Faces (M=59.35%, SD=7.70% vs M=53.93%, SD=8.16%), $t(42)=-2.267$, $p=.029$, $d=-.684$, whereas classification accuracy for Colours was similar between the two groups (TD group: M=63.59%, SD=7.90% vs ASD group: M=65.48%, SD=7.27%), $t(42)=.823$, $p=.415$, $d=.248$, $B_{N(0,6)}=.480$ (the $BF_{10}=.480$ corresponds to $BF_{01}=2.08$, indicating inconclusive evidence for the absence of a group difference). Both groups classified Colours more accurately than Faces. For the ASD group, $t(20)=-6.580$, $p< .001$, $d=-1.436$, and for the TD group, $t(22)=-2.150$, $p=.043$, $d=-.448$.

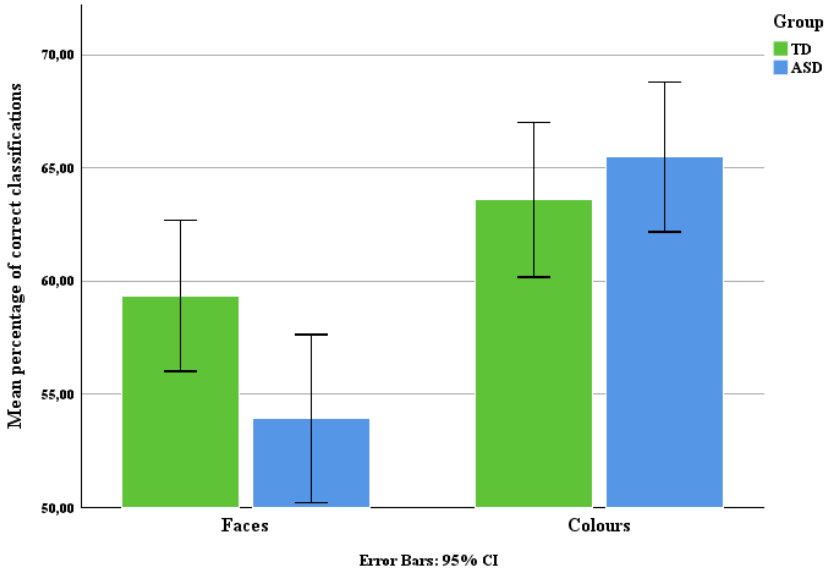


Figure 3. *Mean classification accuracy in the two Stimulus Types for both Groups*

Both TD and ASD groups performed above chance (50%) in both Stimulus Type conditions (Faces and Colours), indicating that learning had occurred regardless of the Type of stimulus (all *p*s< .039).

Attributions of Knowledge

Figure 4 illustrates how frequently each group used implicit and explicit attributions. After applying a multiple comparisons correction (Benjamini & Hochberg, 1995), we found no significant differences between the two groups in either the Faces or the Colours condition separately (all *p*s > .272), or when the two Stimulus Type conditions were combined (all *p*s>.084).

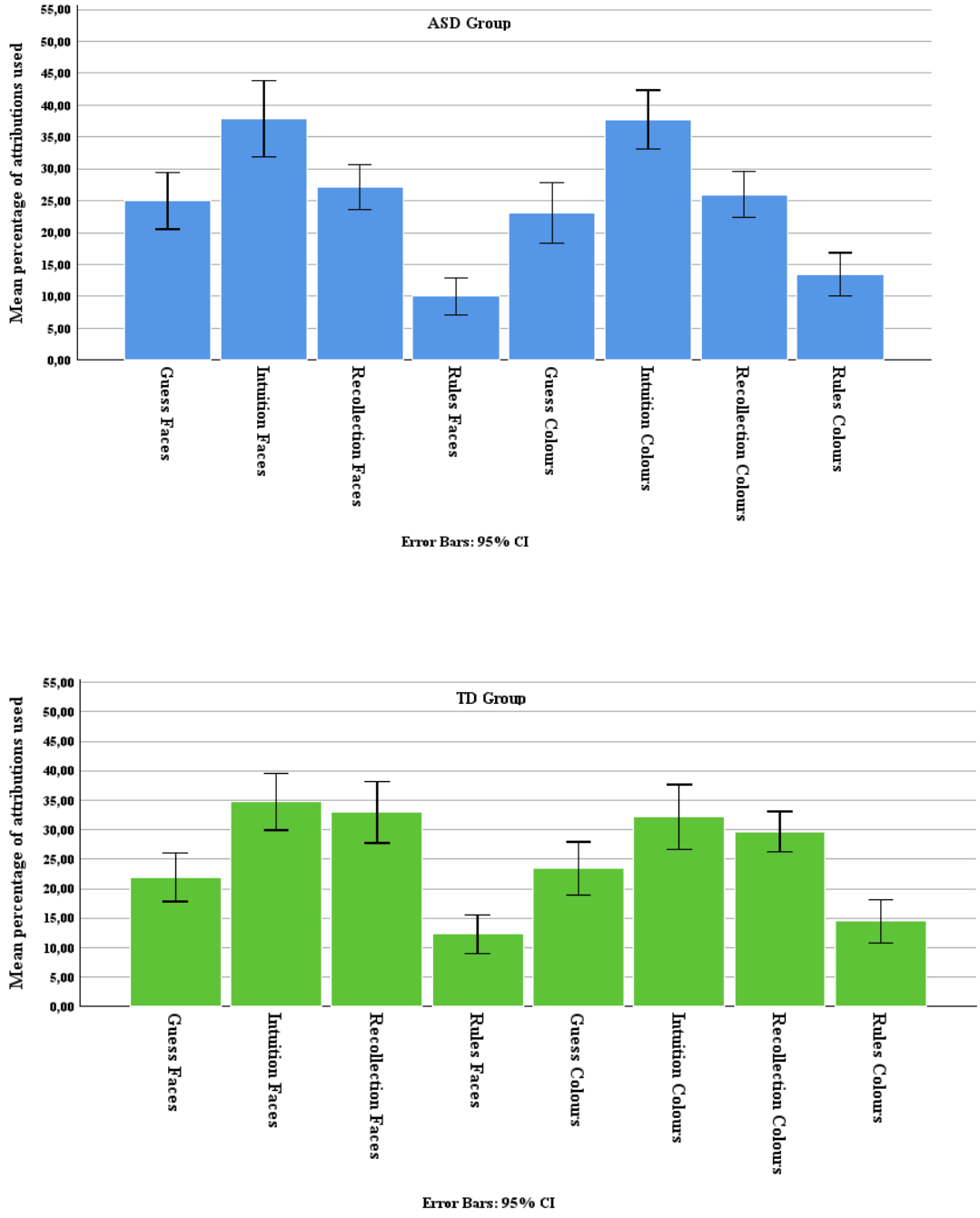


Figure 4. *Relative frequency of the decision attributions selected by the two groups in each Stimulus Type condition.*

Accuracy by type of knowledge attribution

To examine implicit and explicit structural knowledge, we calculated participants' classification accuracy for each Group and each Stimulus Type based on the type of attribution reported. Because some participants used certain attributions in only a small number of trials, mean accuracy scores could be based on very few responses and therefore be unreliable. To reduce this issue, and following previous work (e.g., Kiyokawa et al., 2012; Li et al., 2013; Ziva et al., 2026), the following Bayesian adjustment was applied to all cases in which a given attribution was used at least once:

$$(N_C + 0.5)/(N + 1),$$

where N_C denotes the amount of correct responses and N the total response count.

Moreover, as done in Dienes and Scott (2005; see also Kiyokawa et al., 2012; Li et al., 2013; Ziva et al., 2026), we formed two categories of attributions, namely an implicit category which included guess and intuition/familiarity attributions and an explicit category with recollection and rules attributions. This grouping helps to minimize the impact of uneven or infrequent use of specific attribution types.

Accuracy of attributions indicating implicit knowledge

The two-way mixed ANOVA examining classification accuracy of attributions reflecting implicit structural knowledge (Figure 5) revealed no significant main effect of Group, $F(1, 42)=.118$, $p=.733$, $\eta_p^2=.003$, $B_{N(0,6)}=.325$ (i.e., $BF_{01}=3.077$, indicating moderate evidence for a null difference between the two groups), but a significant effect of Stimulus Type, $F(1, 42)=25.140$, $p<.001$, $\eta_p^2=.374$, with a greater amount of implicit structural knowledge of Colours compared to Faces (M=63%, SD=8.13 vs M=56.14%, SD=7.95), independently of Group. The main effect of Stimulus Type was modified by a significant Group x Stimulus Type interaction, $F(1, 42)=6.023$, $p=.018$, $\eta_p^2=.125$. The difference in the accuracy of implicit structural knowledge between the two groups did not reach significance for either Faces (TD group: M=58.10%, SD=7.12% vs ASD group: M=54%, SD=8.42%), $t(42)=-1.749$, $p=.088$, $d=-.528$, $B_{H(0,6)}=2.587$ (i.e., the BF_{10} indicated inconclusive data, with a tendency to favor a group difference towards the expected direction) or Colours (TD group: M=61.68%, SD=8.37% vs ASD group: M=64.45%, SD=7.79%), $t(42)=1.131$, $p=.264$, $d=.34$, $B_{N(0,6)}=.654$ (i.e., $BF_{01}= 1.529$, providing inconclusive evidence for a null group difference). However, the ASD group classified Faces less accurately

than Colours, $t(20)$=-5.260, p<.001, d=-1.148, whereas for the TD group, classification accuracy was similar in both the Faces and Colours conditions, $t(22)$=-1.823, p=.082, d=-.380, $B_{N(0,6)}$=1.401 (i.e., BF_{01} = .714, indicating inconclusive evidence for a null difference between the two stimulus types).

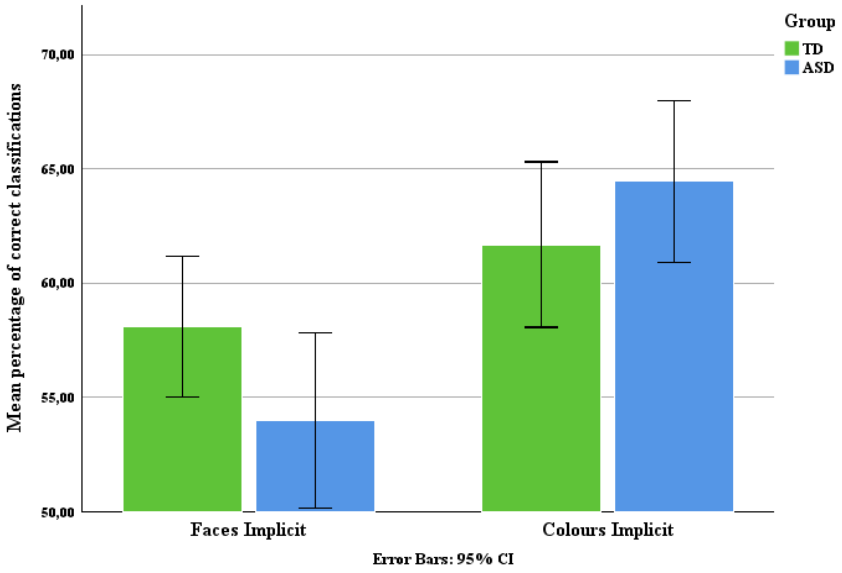


Figure 5. *Mean accuracy of implicit structural knowledge for each Group and Stimulus Type condition.*

Classification of both the ASD and TD groups exceeded chance (50%) significantly when using implicit structural knowledge in both the Faces and the Colours conditions (all *p*s<.042).

Accuracy of attributions indicating explicit knowledge

The 2 x 2 mixed ANOVA on classification accuracy of attributions reflecting explicit structural knowledge revealed no significant between group differences, $F(1, 42)$=1.531, p=.223, η_p^2=.035, $B_{N(0,6)}$=.728 (i.e., with BF_{01}=1.374 suggesting inconclusive evidence for a null difference between the two groups), but significant Stimulus Type differences, $F(1, 42)$=27.479, p<.001, η_p^2=.396, indicating increased classification accuracy for Colours compared to Faces (M=65.64%, SD=9.60 vs M=56.90%, SD=10.79), independently of group. The two-way interaction was also significant, $F(1, 42)$=8.412, p=.006, η_p^2=.167. As can be seen in Figure 6, the TD group outperformed the ASD group when classifying Faces (M=60.71%, SD=10.37 vs M=52.72%, SD=9.84), $t(42)$=-2.615, p=.012, d=-.789, whereas the two groups showed comparable performance in the Colours condition (TD group:

M=64.72%, *SD*=10.0% vs ASD group: *M*=66.65%, *SD*=9.25%), *t*(42)=.663, *p*=.511, *d*=.200, $B_{N(0,6)}$=.521 (i.e., BF_{01}=1.919, indicating inconclusive evidence for a null group difference). Within-group comparisons further demonstrated that, when using explicit structural knowledge, autistic participants classified Colours significantly more accurately than Faces, *t*(20)=-6.344, *p*<.001, *d*=-1.384, whereas the TD group performed similarly in both Stimulus Type conditions, *t*(22)=-1.552, *p*=.135, *d*=-.324, $B_{N(0,6)}$=1.089 (i.e., BF_{01}=.918 indicates inconclusive evidence for the null difference between the two stimulus types).

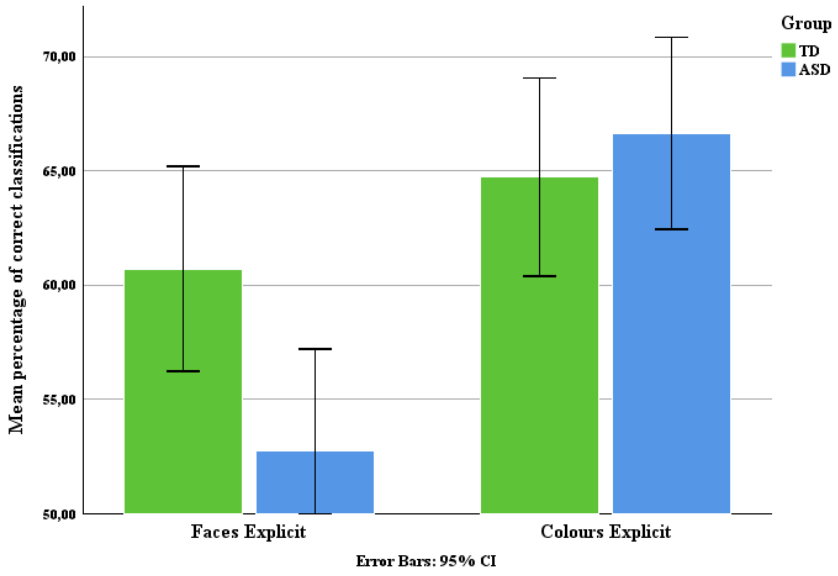


Figure 6. *Mean accuracy of explicit structural knowledge for each Group and Stimulus Type condition.*

When testing whether classification accuracy based on explicit structural knowledge exceeded chance performance (50%), we found that the ASD group's performance significantly exceeded chance only in the Colours condition (*M*=66.65%), *t*(20)=8.246, *p*<.001, *d*=1.799, and not in the Faces condition (*M*=52.72%), *t*(20)=1.269, *p*=.219, *d*=.277, $B_{H(0,6)}$=1.217 (i.e., the BF_{10} indicates inconclusive evidence for above chance performance in this condition). By contrast, the TD group's performance significantly exceeded the 50% chance level in both the Faces (*M*=60.71%), *t*(22)=4.954, *p*<.001, *d*=1.033, and the Colours condition (*M*=64.72%), *t*(22)=7.054, *p*<.001, *d*=1.471.

Correlations

Correlational analyses were performed to examine potential associations between participants' individual characteristics (i.e., age, WASI scores, and CARS scores) and performance

in terms of overall classification accuracy and accuracy for implicit and explicit attributions in the Faces and Colours conditions. After applying the Benjamini–Hochberg method (1995) to control for the false discovery rate during multiple comparisons, none of the correlations reached statistical significance (all *p*s > .108), suggesting that these individual factors were not reliably related to learning performance in the present sample.

Discussion

In the present study, we directly compared the implicit (and explicit) learning of social (faces) and non-social (colours) material in young autistic and TD individuals, in order to examine potential differences in the processing of the two stimulus types between the two groups. Specifically, we used an AGL task in which each element of the sequence comprised a coloured face, assuring that both the social and non-social information were embedded within the same sequence item. This allowed us to investigate the learning of social vs non-social patterns in autistic and TD participants, when both types of information were presented simultaneously. In addition, the study examined the (un)unconsciousness of the product of learning by distinguishing between implicit and explicit structural knowledge using sensitive awareness measures.

Based on the broader literature on social cognition as well as on implicit learning in autism, we did not expect a global impairment in the implicit learning of autistic participants, but rather a disadvantage in processing socially relevant vs socially irrelevant stimuli in the autistic group in contrast to the TD group who might demonstrate comparable performance in the two stimulus types -if not better performance for social stimuli.

Our results largely support these predictions. In all three performance indices (i.e., overall AGL performance, implicit and explicit attributions accuracy), independent t-tests in the baseline (i.e., the Colours) condition showed no evidence of between-group differences, lowering the possibility of a generalized processing deficit in autism. In terms of both overall AGL performance and explicit structural knowledge, we also found a pronounced performance drop in the ASD group while processing the socially relevant stimuli (i.e., Faces), as evidenced by the significant two-way interactions. In terms of implicit structural knowledge, a highly complementary pattern unfolded, as only participants with autism demonstrated a performance decrement for socially relevant compared to socially irrelevant stimuli, whereas TD participants demonstrated a comparable performance in the two stimulus types. Importantly, learning occurred for both groups regardless of stimulus type, as

evidenced from the above chance performance for both groups in both stimulus types, indicating that the ability to extract regularities from artificial grammars was preserved in autism. Taken together, the above results from all three indices of performance concur, demonstrating that, compared to the TD group, participants with autism exhibited a relative processing disadvantage for socially-related stimuli rather than a failure to acquire the underlying structure of the grammars.

Our findings concerning overall implicit structural knowledge fit well with the growing body of work suggesting that implicit learning is preserved in autism (Barnes et al., 2008; Brown et al., 2010; Kourkoulou et al., 2012; Németh et al., 2010; Pesthy et al., 2023; Travers et al., 2010; Ziva & Ziori, 2025; Ziva et al., 2026) and contradict with accounts proposing implicit learning deficits in such groups (e.g., Klinger et al., 2007; Mostofsky et al., 2000), as autistic participants showed reliable above-chance performance across stimulus conditions that was comparable to that of TD participants.

At the same time, our results provide a more nuanced picture when considered alongside previous studies that have investigated implicit learning using socially related stimuli in autism. The comparison of our implicit learning results with those of previous studies shows that implicit learning of socially rich information is task- and context-dependent. For instance, Hoof et al. (2025) found a clear deficit in the implicit social sequence learning of ASD adults compared to controls in an interactive task that involved mentalizing; however, under stable social context conditions this deficit was mitigated, whereas under variable social context conditions performance was impaired for both groups. Scott-Van Zeeland et al. (2010) found a generalized impairment in implicit learning, independently of type of trials (social vs. non-social) and the existence of reward, as well as a reduced neural responsiveness to social rewards in children with autism compared to TD children, using a rewarded implicit learning task. Our results are closer to those of Costea (2018), who used an AGL task to find largely preserved implicit learning of facial emotional structures, although in a sample of varying autistic traits rather than a formally diagnosed sample, and with a small negative association between autistic traits and performance. The present findings are also partly in line with Xie et al. (2024), who showed that autistic children can successfully learn social contingencies, although performance may decrease when multiple contextual cues must be integrated.

Overall, any inconsistencies between the findings of prior research and the present one most likely stem from methodological differences and the distinct experimental tasks used

in the different studies, thus pointing to a more context-dependent account of implicit social learning in autism. The collective findings suggest that implicit learning may be preserved when socially relevant information is presented under static structured conditions, such as the ones in the current AGL paradigm (even with a relative decrement in performance). By contrast, motivationally loaded or highly interactive paradigms may place greater demands on social processing mechanisms, thereby posing greater difficulties in autistic groups.

Although the present study did not directly assess attention or motivation, the ASD groups' increased processing difficulty with social information that the overall pattern of the present results revealed is broadly consistent with previous work on social cognition in autism, which has reported reduced attention and responsiveness to socially meaningful stimuli, particularly faces (e.g., Ambarchi et al., 2023; Congiu et al., 2024; Gale et al., 2019; Harrison & Slane, 2020; Vacas et al., 2021). Given that attention affects how perceptual resources are allocated, reduced attention to socially relevant input may partly explain the lower performance in an implicit learning task in which these resources are essential. Similarly, the present findings are also compatible with theoretical accounts such as the social motivation hypothesis (Chevallier et al., 2012), which proposes that autistic individuals may show lower motivation to orient towards and engage with social material. From this perspective, if social information carries less intrinsic value for people with autism, it may receive lower processing priority, resulting in fewer attentional resources being allocated to socially relevant stimuli and, consequently, in less efficient learning of social regularities in comparison to socially neutral regularities.

However, weaker learning of socially relevant material may not necessarily reflect reduced social attention or motivation alone. Contrary to colours, which constitute simple perceptual features, faces are inherently more complex (see e.g., George, 2016; Maurer et al., 2002) and may be particularly challenging for autistic individuals (e.g., Dawson et al., 2005; Griffin et al., 2021). Therefore, it is possible that the increased processing demands associated with facial information may draw cognitive resources away from the core requirement of the task. Because successful performance in an AGL task depends on the ability to identify the underlying grammatical rules governing the sequences, allocating more cognitive resources to processing faces may leave fewer resources available for tracking the relationships between sequence elements, resulting in less efficient learning of the underlying grammar. A comparable interpretation was proposed by Ziori and Dienes (2015),

who suggested that facial attractiveness (and increased attention to facial features and primarily to the features of attractive faces) may have acted as a distractor that reduced attention to the sequential regularities and thereby performance in an AGL study with TD adults. In the present study, it is possible that faces may have functioned in a related way, thereby interfering with the extraction of sequential regularities, particularly in the autistic group.

A similar explanation for the reduced learning of socially relevant stimuli in autism relates to a bias of autistic individuals towards detail-focused processing (e.g., Happé & Frith, 2006; Mottron et al., 2006; Ziva et al., 2026). Rather than focusing on the order in which faces appeared across the sequences, which would lead to successful performance in the AGL task, autistic participants may have focused more on isolated facial characteristics within the individual sequence elements. Therefore, a possible prioritization of facial details over the order of the faces within a sequence may represent a potential explanation for why learning in the ASD group was less efficient in the Faces condition, despite generally preserved learning abilities.

With respect to our finding of reduced explicit structural knowledge for social input in participants with autism, a possible explanation may be in terms of theories of conscious knowledge accessibility. According to the framework of consciousness proposed by Cleeremans and Jiménez (2002), implicit learning functions without conscious awareness, enabling individuals to extract regularities even when their representations are weak and of low quality, whereas explicit learning develops gradually as these representations improve with learning. Therefore, conscious access to knowledge depends on how strong and stable the underlying representations are. In the present study, potential factors such as reduced attention to facial information, greater processing demands associated with social stimuli, or a tendency to focus on facial details rather than sequential relationships may have limited the quality of the representations formed for facial sequences. From this perspective, autistic participants may have acquired social regularities at an implicit level, but these representations may not have been sufficiently robust to form high-quality knowledge. Consequently, although some learning occurred, the acquired knowledge may not have reached the threshold required for explicit reportable knowledge.

In line with the meta-analysis of research by Hinz et al. (2024), we found no reliable differences between autistic and TD participants in the non-social stimuli condition across all analyses. Importantly, however, the non-social stimuli used in the present study, namely colours, are considered neutral and not related to restricted or circumscribed interests. Hinz

et al. (2024) showed that individuals with autism may demonstrate a relatively enhanced preference for stimuli associated with their restricted interests, such as geometric patterns or mechanical objects. Future research could examine whether implicit and explicit learning are differentially influenced by the motivational relevance of non-social stimuli, particularly those that are highly salient or rewarding for autistic individuals.

Finally, in this study, we examined whether age, intellectual ability (IQ), and autism diagnostic scores were associated with overall AGL task performance and accuracy of implicit and explicit knowledge attributions. In agreement with a substantial portion of the existing literature on implicit learning in autism, our results showed no reliable associations between these individual characteristics and learning performance (e.g., Brown et al., 2010; Kourkoulou et al., 2012; Travers et al., 2013; Ziva & Ziori, 2025; Ziva et al., 2026), indicating that the observed between-group differences in performance are unlikely to be explained by variations in age, IQ, or autism symptomatology. Crucially, because the present groups were matched on age and IQ, and because the autistic sample primarily included individuals with mild to moderate symptoms, the absence of meaningful relationships between these factors and learning performance should be interpreted considering the sample characteristics of the present study.

In conclusion, the present study contributes to a clearer understanding of implicit learning in individuals with and without autism by highlighting the role of stimulus type in shaping learning outcomes. Rather than indicating a general impairment in learning, the findings suggest a more pronounced difficulty while processing socially relevant compared to socially irrelevant stimuli in individuals with autism in comparison to TD individuals. Autistic participants acquired the sequential regularities in both stimulus type conditions, indicating broadly preserved implicit learning of structure overall. However, social information appeared to be processed less efficiently and with decreased conscious awareness in the autistic group. Future research is needed to further clarify the mechanisms that may underlie this pattern, including the potential roles of attention and task demands, as well as to examine whether similar effects are observed across different types of social information and learning contexts.

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Chapter 5

General Discussion

The present thesis aimed to develop a broader account of implicit learning in autism by moving beyond the question of whether implicit learning is simply intact or impaired in people with this condition. Prior work has produced evidence for both outcomes (intact: e.g., Brown et al., 2010; Pesthy et al., 2023; Treves et al., 2024; impaired: e.g., Klinger et al., 2007; Mostofsky et al., 2000), and this inconsistency suggests that implicit learning should not be conceptualised as an ability that is either present or absent. Instead, learning outcomes may depend on a range of factors that the existing literature has left largely unexplored. Accordingly, this thesis followed this line of reasoning, beginning with the fundamental question of whether individuals with autism retain their implicit learning skills and then examining whether specific factors associated with autistic cognition, particularly the processing tendencies of the learner and the social nature of the to be processed stimuli, influence implicit learning performance in autistic groups.

A central aim of Study 1 (see Chapter 2) was to investigate whether implicit learning is preserved in autism, and specifically whether this extends to autistic participants drawn from a wider range of the spectrum, rather than the narrower, high-functioning samples used in most relative studies. The results from the AGL paradigm used in Study 1 confirm that individuals with autism retain the ability to extract implicit knowledge from an artificial grammar. Although their overall AGL accuracy was reduced compared to that of the age- and gender-matched TD group, both groups acquired knowledge of the grammar, including knowledge that was not accompanied by conscious awareness of the underlying grammar rules.

The no-loss gambling method (Dienes & Seth, 2010) contributed to this conclusion by assessing unconscious knowledge through the guessing and zero-correlation criteria (see Dienes et al.,1995). Both groups performed above chance on correct low-confidence judgements, supporting the guessing criterion, while the zero-correlation criterion provided further evidence that learning was not accompanied by conscious knowledge of the grammatical patterns.

A further contribution of Study 1 concerns the relationship between implicit learning and salient features of autism, building on previous research that has mainly used high-functioning autistic participants (e.g., Németh et al., 2010; Treves et al., 2024; Xie et al.,

2024; but see Gordon & Stark, 2007) by examining implicit learning across a broader range of the autism spectrum. Implicit knowledge was not reliably related to intellectual ability or autism symptom severity, which adds further support to the view that implicit learning is a robust mechanism which operates despite substantial variation in other aspects of cognitive functioning.

Most notably, Study 1 offered initial indication that individual processing style, that is, the tendency to attend to either global or local information, may be relevant to implicit learning. Performance on AGL tasks may reflect reliance on rule-based regularities as well as judgments regarding the overall similarity between learning and test sequences (e.g., Opitz & Hofmann, 2015; Ziori & Pothos, 2015). The design of Study 1 could not distinguish between these underlying knowledge structures directly, so the relationship between processing tendencies and AGL performance was examined on an exploratory basis, using a separate Navon-type task (Navon, 1977), and participants' performance was then correlated with their AGL performance.

Results from the Navon task revealed a marked global processing advantage in the autistic group, contrary to the predictions of both the WCC (Frith & Happe, 1994) and the EPF (Mottron et al., 2006) accounts, which generally anticipate a bias toward local processing in autism. This finding is consistent with earlier reports of a global advantage under comparable conditions (Hayward et al., 2012; Mottron et al., 1999), as well as with findings from selective-attention paradigms that do not favor spontaneous processing tendencies (Plaisted et al., 1999). Therefore, the results suggest that global–local processing in autism may depend more on task characteristics and attentional demands than on fixed processing biases.

With respect to the relationship between the AGL and the Navon performance, exploratory analyses showed that, within the TD group, a weaker global advantage was associated with better AGL performance. This finding raises an important possibility about why implicit learning may have been reduced in the autistic group. If successful AGL performance depends, at least in part, on attending to the local elements of the items, then the difficulties with local processing observed in autistic participants may have resulted in lower implicit learning performance. In addition, their stronger global processing tendency may have further shifted attention away from information that was important for learning the underlying rules. Of course, this interpretation requires further support, as the associations were ex-

ploratory, emerged only within the TD group, and were based on correlations between separate tasks. Nevertheless, these findings provided some initial support for the hypothesis that processing tendencies may affect implicit learning. This hypothesis was further tested in the second study of this thesis.

Study 2 (see Chapter 3) built on Study 1 by examining whether processing tendencies contribute to variability in implicit learning in autism. While Study 1 assessed implicit learning and processing tendencies in separate tasks, Study 2 embedded global and local structures within the same AGL task using GLOCAL sequences (Tanaka et al., 2008). Importantly, participants in this study were not instructed to attend to either level, allowing them to process the sequences according to their naturally preferred mode.

The second study also extended the awareness methodology used in the first study by providing a more specific assessment of the consciousness of the knowledge acquired during the AGL task. Using a trial-by-trial attribution measure (Dienes & Scott, 2005) and a separate recognition test focusing primarily on explicit fragment knowledge, the study was able to disentangle implicit and explicit contributions, providing a more detailed assessment of what participants had learned about the global and local structures and whether this knowledge was consciously accessible.

The central finding of Study 2 was that the processing tendencies of the learner may contribute to differences in implicit learning outcomes. More specifically, although global processing was clearly present in autistic participants, implicit learning of global regularities was reduced compared to that of a TD group, whereas learning from local information did not differ reliably between groups. Notably, the results of Study 2 do not support a general difficulty with global processing or a local-processing advantage for the autistic group. Instead, the overall pattern of findings implies that the level of processing given greater priority during implicit learning may shape how successfully knowledge is acquired when global and local stimuli are presented together.

One possible explanation for the observed pattern is that autistic and TD individuals may differ in how they distribute attention across the two levels of processing. When attention is not explicitly directed towards a specific level, autistic individuals may allocate relatively more attention to local stimuli, giving global information lower priority during learning. From this perspective, global processing would remain functional but would operate more as a secondary source of learning. This interpretation is largely consistent with

the EPF account (e.g., Mottron et al., 2006), but it should be treated as a possible explanation rather than a standard mechanism. Importantly, Study 2 did not directly measure where participants directed their attention or how attentional priority changed during learning, so this interpretation should be further tested. Direct measures, such as eye-tracking methods, could help determine whether differences in the distribution of attentional sources contribute to the observed pattern of global and local implicit learning in the autistic group.

The explicit knowledge and recognition task findings provided some further indication of a related pattern regarding conscious awareness, with autistic participants showing no explicit knowledge and only marginal recognition of information at the global level. This raises the possibility that information given lower priority during learning may also be less accessible to conscious awareness.

Study 2 also helps to refine the interpretation of Study 1. More specifically, in Study 1, the reduced local processing observed in the autistic group, together with the weaker implicit learning performance, initially implied that challenges in local processing may contribute to reduced implicit learning. However, in Study 2, when both global and local stimuli were incorporated directly into the learning task, participants with autism were able to learn the local regularities as well as TD participants, but their implicit learning of global structures, although evident, was weaker compared to that of their TD peers. This suggests that a simple explanation in which reduced local processing results to weaker implicit learning is difficult to support.

The findings of Study 2 may also help explain some of the inconsistency observed in previous work. Implicit learning paradigms differ substantially in how information is organised and presented, creating different learning conditions. Therefore, the relative importance of global and local information may vary depending on which level is more useful for the demands of a particular task. In turn, this may influence how individuals distribute attention across levels and which regularities are acquired more successfully. Differences in global–local processing may consequently emerge differently across tasks, depending not only on individual processing tendencies but also on how the learning environment is structured and how the instructions given to participants direct attention. From this perspective, contrasting findings may sometimes reflect differences in the conditions under which learning takes place, rather than differences in implicit learning ability.

The pattern across the first two studies also suggests that characteristics such as IQ and autism symptom severity may not provide a strong explanation for the variability in implicit

learning. In Study 2, neither characteristic showed a reliable association with overall performance, implicit or explicit knowledge.

In all, Study 2 reinforces the view that variability in implicit learning in autism may depend on other factors associated with autistic cognition beyond IQ and autism symptom severity. The findings suggest that how information is processed may influence implicit learning in autism, with differences in processing tendencies potentially affecting which regularities are learned more efficiently. This provided a basis for examining another characteristic relevant to autism, namely possible differences in the processing of socially meaningful vs non-social information. Therefore, Study 3 (see Chapter 4) followed the processing perspective developed in Study 2 by asking whether the type of information being learned, specifically its social vs non-social nature, may influence implicit learning in autism.

More specifically, Study 3 examined how the social vs non-social nature of the stimuli affects implicit learning in autistic and TD individuals. This dimension is particularly relevant to autism, given that differences in social communication and interaction are central to the condition (APA, 2013). Although extensive research has examined social information processing in autism (e.g., Chevallier et al., 2012; Gale et al., 2019; Sasson & Touchstone, 2014; Vacas et al., 2021), direct evidence on whether the social nature of information influences implicit learning in autistic individuals has remained limited (Costea, 2018; Scott-Van Zeeland et al., 2010). To address this gap, Study 3 examined whether social vs non-social information represents another context in which implicit learning may vary between autistic and TD individuals. To this end, the study included both social (faces) and non-social (colours) structures within a single AGL task, using the same trial-by-trial awareness measure as in Study 2 to distinguish between implicit from explicit knowledge.

Study 3 showed that social information processing represented a more challenging context for autistic participants than non-social information. Although the two groups learned regularities from both stimulus types, participants with autism showed weaker performance when learning sequences of faces, whereas TD participants performed more similarly across conditions. This pattern was evident in overall, implicit and explicit learning performance, but it was more pronounced for explicit learning. Notably, in the social condition, autistic participants did not demonstrate explicit knowledge, despite showing above-chance implicit knowledge. A comparable finding was observed in Study 2, where participants with autism showed no explicit knowledge of global stimuli and weaker recognition-based

knowledge for global regularities despite demonstrating implicit learning at that level. Therefore, this finding strengthens the possibility that learning may occur without becoming consciously accessible, as knowledge can vary in strength and influence behaviour before reaching conscious awareness.

The greater difficulty experienced by autistic participants when learning the social stimuli may reflect several factors. Previous research has documented differences in how autistic individuals process socially meaningful information, particularly faces, including differences in attention to and engagement with social stimuli (e.g., Congiu et al., 2024; Griffin et al., 2021). Although, the contribution of attention allocation and motivation cannot be determined, as neither was directly assessed here, it is possible that the reduced attention to or engagement with social material have limited the ability for extracting the sequential regularities required by the task. At the same time, faces contain more complex perceptual information than colours and may therefore require greater processing effort from autistic participants. Therefore, the reduced learning observed for faces in the autistic group may not be attributable solely to the social content of the stimuli, but could instead reflect the combined influence of social and perceptual demands.

The findings of Study 3 can also be considered in relation to the processing-priority interpretation provided in Study 2. Study 2 suggested that when global and local information are presented together, differences in the relative priority given to a particular level of processing may influence which regularities are learned more efficiently. For the autistic group, a related interpretation may help explain the reduced learning observed for faces in this study, where the processing of facial features could compete with the processing of the relationships between successive stimuli that are relevant for extracting the grammar. This would provide a common framework for interpreting the two studies, while recognising that the competing sources of information differ. In Study 2, the competition concerned different levels of the same stimuli, whereas in Study 3, it may have involved the perceptual and social characteristics of the stimuli alongside the sequential structure that participants needed to learn. Finally, extending the pattern observed in Studies 1 and 2, Study 3 provided no evidence that IQ or autism symptom severity was not associated with learning outcomes.

Overall, Study 3 suggests that the type of information being learned may affect implicit learning performance in people with autism. When regularities were associated with socially meaningful stimuli, autistic participants showed greater difficulty in extracting them than when the same learning demands involved non-social stimuli. At the same time, the

presence of above-chance implicit learning of faces indicates that this greater difficulty did not eliminate learning. Rather, the findings suggest that social context can substantially influence the efficiency with which regularities are acquired, while the ability to learn those regularities remains present.

Collectively, the three studies examined whether implicit learning is preserved in young autistic participants with a wider range of intellectual ability and symptom severity than those most commonly used in prior research, and whether individual characteristics associated with autistic cognition -specifically differences in the processing of global and local information and the social nature of the information being learned- influence how regularities are acquired. Study 1 established that participants with autism were able to acquire regularities implicitly, while also proposing that differences in processing tendencies might be relevant to how well rules and patterns are implicitly learned. Study 2 provided a more direct examination of this possibility by incorporating both global and local structures within an AGL task. The findings showed that participants with autism could learn at both levels, but that global regularities contributed less strongly to implicit learning than they did for TD participants, potentially because global information received lower priority when global and local regularities were presented together. Study 3 then extended this reasoning by examining whether the type of information being learned also influenced implicit learning, focusing specifically on its social relevance. Learning from social material was more difficult for autistic participants than learning from non-social material, although they still showed evidence of implicit learning in the social condition. Taken together, the studies show that, although individuals with autism can extract regularities implicitly, the extent to which different types of information contribute to learning can vary according to how that information is presented to and prioritized by participants, depending on their processing biases, preferences or difficulties. The findings of the three studies are discussed below in relation to their theoretical significance, practical implications, limitations, and directions for future research.

Theoretical significance

The theoretical contribution of this thesis lies in showing that implicit learning in autism cannot be reduced to a simple question of whether this type of learning is preserved or impaired. Across the three studies, and notably by including autistic participants across a broader range of intellectual ability and symptom severity than that used in most prior work,

we consistently found evidence of implicit learning in autism, even when their learning performance differed from that of TD participants. At the same time, it appears that implicit learning may operate differently across different contexts, and its expression may depend on other factors, particularly on how information is processed and what type of information is being learned, factors that the present thesis specifically set out to examine.

Study 1 first raised the possibility that global–local processing tendencies might be relevant, and Study 2 tested this more directly by embedding both levels within the same learning task. The finding that global regularities were learned less efficiently by the autistic group, despite being learned above chance, suggests that the relative priority given to different levels of information during learning may be important for understanding differences in implicit learning between autistic and TD individuals. This provides a more specific interpretation of the global–local findings than a simple distinction between global and local processing ability, as both levels could be learned by autistic participants but did not contribute equally to learning.

Study 3 points to a further factor, the social nature of the information being learned. Participants with autism showed a clear reduction in learning specifically for social stimuli, while their learning of non-social stimuli remained comparable to that of TD participants. This pattern suggests that the nature of the information being learned can also shape how efficiently regularities are acquired. In particular, learning from socially meaningful information appeared to place greater demands on autistic participants than learning from non-social information, even though socially relevant regularities could still be acquired.

Taken together, these findings support a more specific theoretical position than the one a simple intact-versus-impaired framing allows. In a wide range of autistic samples, implicit learning appears generally preserved, yet its efficiency is sensitive to identifiable characteristics of the learning context. Across the present studies, these characteristics concerned the more holistic or more detailed level at which information was processed and the social or non-social nature of the to be learned material. Thus, the findings suggest that differences in implicit learning in autism are not simply a matter of whether the capacity to learn regularities is present, as this capacity depends strongly on the conditions under which it is expressed.

Implications for cognitive psychology and research on autism

From the perspective of cognitive psychology, the present findings contribute to a broader

understanding of implicit learning as a process that is both robust and sensitive to context. The relative preservation of implicit learning across different participant characteristics and experimental conditions supports the idea that the mechanisms responsible for extracting rules and patterns may be evolutionarily old and comparatively resilient. At the same time, the differences observed in global vs local processing and in social vs non-social learning demonstrate that the operation of this system cannot be understood independently of attention, perceptual organisation, and stimulus characteristics.

For researchers investigating cognition, and particularly implicit learning in autism, this suggests that future studies should move beyond simple comparisons of mean performance between autistic and TD groups. A more informative approach may be to examine the conditions under which learning is more or less successful. This could involve systematically manipulating processing level, stimulus complexity, social relevance, attentional demands, and motivational value. Such an approach may help explain why studies using apparently similar implicit learning paradigms often produce different outcomes.

The present thesis also highlights the value of incorporating sensitive measures of consciousness into implicit learning paradigms, something that many prior studies did not take into account. Distinguishing between implicit and explicit knowledge can reveal differences that would remain hidden if only overall task accuracy were considered. This is particularly important in autism research, where differences in conscious strategy use, attention, or verbal reporting may influence performance independently of the underlying ability to learn regularities.

Moreover, the studies of this thesis point to the value of sampling more widely across the autism spectrum than has typically been the case. By including participants with greater variation in intellectual ability and symptom severity, as in Study 1, the thesis showed that evidence for implicit learning, and its relative independence from IQ and symptom severity is not limited to the more narrowly selected samples typically represented in relevant literature. This suggests that findings based on restricted samples may not generalise across the full range of individuals with the condition. Future research would therefore benefit from deliberately recruiting more heterogeneous samples, rather than treating limited variability in characteristics such as IQ as an inherent methodological advantage.

Finally, these findings have implications for how implicit learning is conceptualised. The present findings show that implicit learning should be considered independently of the information from which regularities are learned. Differences in the level of (detailed vs

holistic) processing of information and in its social vs neutral content were associated with differences in implicit learning. This suggests that characteristics of the information being processed are not simply features of the task but may influence how implicit learning is expressed across different groups. This point concerns not only autism research, as similar influences may contribute to variability in implicit learning more generally. Future research in cognitive psychology may therefore benefit from treating processing level and stimulus characteristics as important variables in their own right, rather than as incidental features of task design.

Potential applications

Although the three studies included here were not designed as intervention studies, their findings may have useful practical implications. First, they suggest that the preserved implicit learning ability observed in autistic participants could potentially be used in educational and intervention contexts, as learning does not always need to depend on explicit instruction or the conscious verbalisation of rules. At the same time, the findings suggest that the design of the learning environment matters. Information may be more readily learned when the aspects that are relevant to learning are easy to identify, competing sources of information are minimised, when the to be learned material attracts attention or is prioritized according to preferences or biases, and when the task does not impose unnecessary perceptual or attentional demands beyond those required for learning.

The findings may also be informative for educators and practitioners supporting social learning in individuals with autism. The reduced learning observed for facial information suggests that social learning in autism may benefit from carefully structured learning environments in which the relevant social information is clear and not obscured by perceptual complexity. Because the faces used in the present study combined social meaning with considerable perceptual detail, future research could examine whether reducing the unnecessary perceptual complexity of social information, while keeping its social content intact, improves learning.

More broadly, the findings suggest that implicit learning may provide a route through which autistic individuals can acquire knowledge, including those with lower intellectual ability or more pronounced symptom severity, and this may be practically useful in situations where learning cannot depend entirely on explicit instruction, verbal explanation, or conscious understanding of the rules being taught. For example, learning activities could

incorporate repeated exposure to routines or examples so that learners have opportunities to gain knowledge through experience without being expected to acquire or explain it explicitly. This principle could potentially be applied to areas such as classroom routines, vocabulary and language learning, procedural skills, and aspects of social understanding, where repeated experience may allow useful knowledge to develop. In this way, implicit learning could be viewed not as a replacement for explicit teaching, but as an additional means through which learning can take place.

Limitations and generalisability

Several limitations should be considered when interpreting the findings of the present thesis as a whole. First, all three studies relied on AGL paradigms. Although the AGL task offers a powerful method for studying implicit learning under controlled conditions, and although Studies 1 and 3 used ecologically valid and socially relevant stimuli, artificial grammatical structures differ considerably from the regularities encountered in everyday life; so how far the present findings generalise to more naturalistic learning remains uncertain. Second, the samples differed in important ways across studies, and the characteristics of the autistic participants necessarily constrain the populations to which the findings can be generalised. Studies 2 and 3 included young participants with relatively mild to moderate symptomatology, or with a relatively narrow range of intellectual ability, whereas Study I included children and adolescents with lower intellectual abilities and greater symptom severity. Accordingly, the findings from the different studies should not be assumed to generalise automatically to autistic individuals with substantially different cognitive profiles, support needs, or developmental histories.

Third, although the studies examined potentially important factors related to implicit learning, they did not directly measure the mechanisms that may account for the observed differences. In Study 1, for example, the relationship between global–local processing and implicit learning was examined using performance from two different tasks, so the extent to which the processing tendencies observed in the Navon task were related to learning in the AGL task remains unclear. Study 2 examined global vs local learning within the same task but did not directly assess whether autistic participants spent less time processing the global structure, devoted more sustained attention to local elements, or switched between the two levels differently while extracting the regularities. Similarly, Study 3 revealed differences in learning social vs non-social information without directly establishing which

characteristics of the stimuli or learning context were responsible for these differences. Therefore, across the three studies, the proposed explanations should be treated as plausible interpretations rather than definitive accounts of the findings. More generally, the studies were designed to identify conditions under which implicit learning may differ, rather than to establish the precise cognitive processes responsible for those differences.

Future directions

A key question for future research concerns the cognitive mechanisms that may underlie variation in implicit learning performance. Combining AGL and other implicit learning paradigms with independent measures of cognitive processes such as attention, executive functioning, working memory and/or cognitive flexibility could help determine whether individual differences in these processes are associated with the learning patterns observed here. These measures represent examples of processes that may be relevant rather than an exhaustive set of possible influences. In particular, eye-tracking or similar measures of attentional allocation could help clarify how attention contributes to implicit learning by showing how learners select, maintain, and distribute attention across different sources of information during learning.

The ecological validity of these findings also needs to be established. Future research should therefore move beyond artificial laboratory paradigms towards more naturalistic forms of implicit learning. Examining whether similar patterns emerge when individuals extract regularities in everyday learning situations would help determine whether the context-dependent effects observed here extend beyond tightly controlled experimental settings. Such research could also clarify whether the influence of processing level and the social nature of information observed in the present studies remains evident when learning takes place in richer and more complex contexts.

Finally, the generalisability of these findings needs to be examined across the wider autistic population. Future studies should include more heterogeneous samples, with broader ranges of intellectual ability, symptom characteristics, and age. This would help establish whether the patterns observed here generalise across a wider range of autistic individuals and whether similar differences in learning emerge across different participant characteristics.

Overall conclusion

Taken as a whole, this thesis provides evidence that implicit learning in people with autism should not be understood only as an ability that may be simply intact or impaired. Across different experimental contexts, participants with autism demonstrated the ability to gain implicit knowledge, although their learning performance differed from that of TD participants under particular conditions. Importantly, the different patterns of learning observed between autistic and TD groups were not strongly related to variation in IQ or symptom severity but rather reflect some influence from other characteristics related to autistic cognition. In particular, the individual differences in processing tendencies and the social relevance of the learning material were examined here as two factors that could possibly contribute to differences in implicit learning outcomes between typical and autistic groups. Overall, the present findings suggest that both these factors may be meaningful sources of variability that help explain at least some of the long-standing inconsistencies in relevant literature. Future work can build on this perspective by examining other factors that may contribute to variation in implicit learning in autism as well as the specific conditions under which their role is most evident.

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