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Implicit Learning in Neurotypical and Austism Spectrum Children

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3. Abstract

The present thesis, entitled "Implicit Learning in Neurotypical and Autism Spectrum Children", proposes to present and explore several articles that analyze implicit learning mechanisms. The paper's main goal is not to answer questions – although it might answer those of a simpler nature -, but to ask them: how is implicit learning linked to autism? Why do some implicit processes seem affected by ASD whilst others seem untouched? How well do institutions deal with atypical learning profiles? Of course, it is a wide area of study, and the need for further evidence in the field is unquestionable, but this dissertation is a first attempt at understanding the part implicit learning plays in the atypicality of autistic cognition.

Initially, given that one can not understand differences in autistic cognition without first comprehending typical cognition, the relevant frameworks for implicit mechanisms will be discussed. These are the statistical and rule learning frameworks. Once the definitions and results of typical development research are well-established, then autism spectrum disorder will become the focus of the text. The diagnosis criteria for the disorder, as postulated by the DSM-5, will be brought to light. Then, when a more concrete depiction of the disorder has been built, implicit learning will be revisited – only now in connection with autistic cognition. Finally, given that the institutional body shares great responsibility in the management of autism, some educational interventions will be discussed. The last chapter of the dissertation consists of a conclusion that will review the most relevant findings, with a particular interest in pointing out gaps that are still present in the area of research.

4. Introduction

The passage of each day in an individual's life is marked by incoming information from their environment. Typically, the input considered relevant is properly stocked, and the rest is disregarded. This does not mean, however, that a person consciously judges every stimulus according to its importance, nor that they are aware they are assimilating anything – but that they are constantly learning something, even if sometimes they are not mindful of it. First coined in 1965 by Arthur S. Reber, the term implicit learning refers precisely to the learning processes that occur outside awareness - to the tasks that are learnt, despite the lack of intention in learning it (APA Dictionary of Psychology, n.d.). This "unintentional" type of learning is present in one's life from birth to death and plays a pivotal role in individuals' perception of the world around them, especially during earlier stages of development (Smalle et al., 2018). Phenomena such as language acquisition and socialization, which might seem like skills one acquires consciously, have their foundation in implicit knowledge – so what would it mean for someone to have socialization troubles, for example? Does that imply implicit learning deficits?

Autism Spectrum Disorder (ASD), a developmental condition characterized by aforementioned socialization impairments, could potentially be connected to early implicit learning disparities. Individuals within the spectrum may face challenges in having interpersonal interactions, as well as display repetitive behaviors and exhibit restricted interests (American Psychiatric Association, n.d.), all of which can greatly deteriorate their quality of life. Considering ASD is a disorder generally recognizable before school age (APA Dictionary of Psychology, n.d.), a period in which implicit cognition is notably present, it would not be unreasonable to postulate a link between them – and if such relationship was to be scientifically established, educational interventions could bridge the gap between typically and atypically developing kids.

A scientific initiation published in 2022 by Bettoni and colleagues explored such endeavors by evaluating rule learning in adolescents with autism. As an implicit process responsible for extracting general truths from sequences of events, studying rule learning could provide some insight into the social challenges faced by individuals with ASD. By examining to which degree the ASD population struggles with extracting and generalizing rules from social cues, their difficulties in establishing successful interactions can be better understood (Bettoni et al., 2022). In light of the study, the authors recruited eighteen typically developing adolescents (TD group) and eighteen others who were diagnosed with autism spectrum disorder (ASD group). They all underwent a battery of rule learning tests of three different natures (i, ii, iii):

i. when social stimuli are presented (i.e., faces),
ii. when non-social yet complex stimuli are presented (i.e., inverted faces), and
iii. when non-social stimuli are presented (i.e., geometric shapes).

Even though different results were expected between groups, the results showed comparable performance regardless of the nature of the task (social vs. non-social). Besides that, an association between working memory strategies and rule learning was found in the ASD group and not in the TD population, which suggests that ASD individuals may use a different neurocognitive pathway for the learning of rules.

In conclusion, the concept of implicit learning is a fundamental aspect of human development, and its potential connection to autism spectrum disorder (ASD) is a topic of significant interest. Even if there is not sufficient literature that attributes ASD's social impairments to rule learning deficits (Bettoni et al., 2022), the challenges faced by individuals with ASD in socialization are already well-documented - and the early stages of implicit learning may still play a crucial role in understanding these difficulties. By delving further into the existing literature and exploring potential gaps in current understanding, it becomes clear that there is a need for more in-depth research in this field. The implications of neurodevelopmental discrepancies, if linked to implicit learning, could open up new avenues for educational interventions and support for those on the autism spectrum – and it is this integrated view that this thesis is committed to exploring.

5. Implicit learning

As previously discussed, implicit learning sets the foundation for an individual's proper development. Numerous cognitive processes happen implicitly, and the goal of this chapter is to further discuss the most relevant ones for the purpose of the thesis (i, ii):

i. statistical learning, and
ii. rule learning.

Finally, in order to both exemplify and properly consolidate pertinent research in the field of implicit learning, several studies on typically developing individuals shall be discussed for each relevant framework.

5.1. Statistical learning framework

Statistical learning consists, generally, of the retrieval of statistical regularities or patterns out of one's sensory environment. To put it in other terms, it is the process through which people recognize patterns in numerous environments through their senses. In scientific history, said learning was first examined through the auditory modality. A study conducted in 1996 by Jenny Saffran, Richard Aslin and Elissa Newport illustrates how these auditory regularities are learnt by 8-month-old infants – and how they turn out to be crucial in language acquisition. The authors clarify how typically, for the survival and evolutionary success of a species, cognition can be wired to interpret external stimuli both in an experience-dependent and an experience-independent fashion. This means that sometimes it is more advantageous to have a slow-paced, experience-dependent type of learning than a fast-paced, independent type. In the particular case of language acquisition, it is agreed that both mechanisms are essential to reach fluency – and statistical learning is of vital importance to this process, notably during infancy. In order to further examine this mechanism in infants, Saffran et al. applied a battery of tests that have been widely used when studying the topic. It consists of the production of a speech stream that contains several syllables, all of which are either consistently followed by one another (transitional probability of 1.0) or not always consecutive (transitional probability of 0.33). After exposure, the 8-month-olds showed a process of dishabituation (Turk-Browne, 2012) to new words that, even though were composed of the same syllables, did not have the transitional probability of 1.0. “Dishabituating” happens since the infant is expecting a certain order of syllables to be followed in the speech stream – just as it had been previously -, but the new words do not fit into the established pattern, so the infants spend a longer period of time processing these words. The longer reaction time indicates that statistical learning occurred for the set of exposed regularities, indicating also that one of the primordial processes to attain linguistic development is already present before 1 year of age.

Moreover, even though the auditory modality was the first to be investigated, it is not the only one through which statistical learning occurs. The visual field is also full of patterns that humans start picking up very early on in their development. Let the concept of object permanence serve as an example at this moment. The idea that an object stays where it is unless it is moved is not innate to humans, but rather a concept that develops around the fourth month of age. This means that a 2-month-old could look at a plate, for example, and as soon as it is covered with a towel, they would be certain it was no longer there. However, the species' visual system has been in the making for thousands of years, and eventually, the fact that objects continue to exist even after being occluded would be understood as a physical regularity (Turk-Browne, 2012). Stated regularities make part of the visual patterns that are learnt through implicit processes from an early age, but they are not the only kind – there are others, such as semantic and token regularities. The former makes reference to the meaning and nature of objects and much like physical regularities, they are either built into the visual system or learnt somewhere throughout the development. Take traffic lights as an example: their purpose is the organization of traffic, and they are typically built surrounding roads or streets. If someone was to see one in the middle of a beach, it would be startling since it is incoherent to the semantic regularity of traffic lights. The latter, however, differently from physical or semantic regularities, can be introduced in an experimental setting (Turk-Browne, 2012), which serves a great purpose in the investigation of learning mechanisms. All of the mentioned regularities are said to be symbolic, which means that they focus on the characteristics of individual elements – such as the fact that they emit light and are on the side of roads, in the debated case of traffic lights. Other types of regularities focus on the relationship between elements, or in other words the statistical relationships between them. These are called statistical regularities, and they pave the way for statistical learning.

In a study conducted by Hermann Bulf, Scott Johnson and Eloisa Valenza these aforementioned statistical regularities were used to examine visual statistical learning in newborns. Previous research had established that statistical learning was present in the auditory modality in the same population, so they hoped to discover whether these findings were also applicable to the visual modality. In the research, forty-eight 1 to 3-day-old infants were tested with a continuous sequence of shapes that had no delay between them. Each of the shapes were regularly paired with another one, meaning that each grouping had a 1.0 transitional probability (always followed by one another), whilst in-between groupings had either a 0.33 or 0.5 transitional probability, depending on the condition of testing. The first, "high-demand" condition (HDC), was composed of a stream containing 6 shapes and the second, "low-demand" condition (LDC), of 4. During the habituation phase, the subjects are repeatedly exposed to the stimuli to induce a decreased response to already familiar streams. In this case, it consisted of a square + X shape (1st pair), a circle + hexagon (2nd pair) & a triangle + octagon (3rd pair) for the HDC and a square + X shape (1st pair) & a circle + triangle (2nd pair) for the LDC (**Fig. 1**). The subsequent test phase consisted, then, of a novel sequence that did not conform to the pairings previously made during habituation. Considering that the newborns were properly habituated, the expectations were that they would look longer at the novel sequence since it does not conform to the statistical learning that happened beforehand (evidence that dishabituation occurred). However, the outcome was not completely aligned

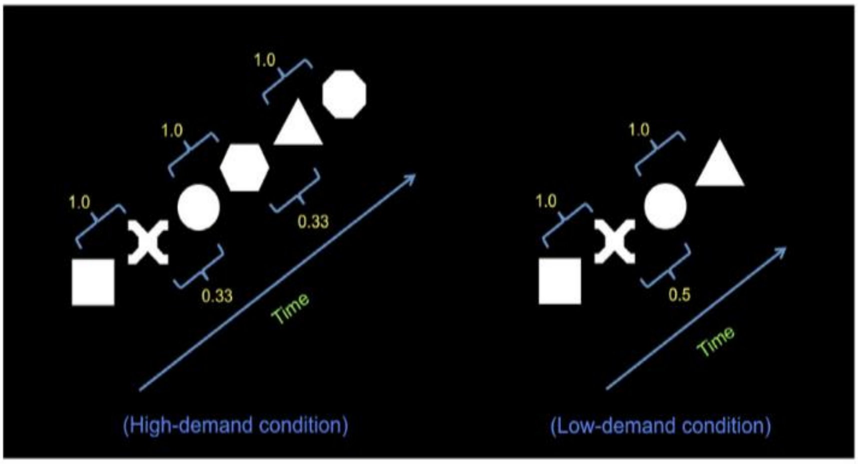

Fig. 1. Schematic representation of the learning sequence presented during habituation in the two experiments, showing transitional probabilities defining pairs (higher within pairs than between pairs).

with the scientists' expectations. When measuring the results, statistical learning was observed only in the LDC - since it was only in this condition that the babies looked for a longer period of time towards the novel sequence than to the familiar one. For the HDC, the newborns looked for a slightly smaller period of time towards the novel sequence, which signifies that their performance in this condition dropped to chance (Bulf et al., 2011). This could be due to the excessive complexity of the task in addition to their limited cognitive abilities at this age. In discussing the topic, the authors recognized three potential constraints for the babies' performance at the high-demand condition: memory limitations, a more effective habituation at the low-demand condition, or a selective attention matter. Overall, the study successfully extended statistical learning in infants to the visual modality, and it also exposed its constraints – finding that had never been previously attained. In the scope of the present thesis, the study also effectively illustrated the quickness and efficiency of statistical learning processes in typically developing children.

5.2. Rule learning framework

Rule learning, much like statistical learning, is a mechanism that helps an individual make sense of the world. It involves the recognition and generalization of patterns, but not statistical patterns as in the previously discussed framework. These are rule-like patterns that are built to fit new elements of the same nature. A palpable example of this mechanism is, once again, language acquisition. Every language has a very complex structure which is understood in significant part thanks to rule-learning processes. For instance, if a native speaker of english was to be asked to explain the structure of a sentence, they might not know the grammatically supported answer, but simply know which is the correct way of phrasing it. They are so familiar with english that they do not even have to think to speak, they just do, and it turns out right. That is partly because english's rule-like patterns have already been recognized by this speaker, and no matter what sentence they want to say, they can generalize these rules to form a new, grammatically correct sentence. For research purposes, in order to examine rule-learning, scientists frequently refer to two rule-like patterns: ABB and ABA. The former refers to elements that are grouped up in an ABB fashion, which means that the first element is A, followed by a pair of B's. The latter, ABA, has element A be followed by element B and then again by another A. Of course, in this simplified experimental model, alphabetical letters are used in order to represent other elements, which in research settings vary greatly depending on the focus of the study. For example, if faces are used as the visual elements to be studied, there is a social factor that has to be taken into account when interpreting results. It is important to clarify, as well, that rule-learning has been examined not only for visual stimuli, but also in the auditory modality. Speech streams were investigated before any visual stimulus was introduced in experimental settings, just as in the case of statistical learning. A study held in 1999 by Marcus et al. strove to better understand language acquisition at the early age by investigating the learning mechanisms that enable a young child to start their journey with languages. From the starting point, it was established that statistics played its role in language acquisition (Saffran et al., 1996) but there seemed to be another - more algebraic - mechanism through which kids were rapidly learning. The authors evaluated the 7-month-olds in three different tests, all specifically designed to be solved by rule-learning mechanisms – so the recognition of transitional probabilities and/or counting strategies could not suffice by themselves in the completion of each test. In all three of them, the infants were habituated to a speech stream of three words of an artificially created language and successively tested with another three-word stream of new artificial words. The combination of the three experiments was held in order to assure that any observed result was not reliable nor on phonetic features of the streams nor on other processes that could occlude rule-learning from being the main mechanism used. That way, it is assumed that any infant who correctly generalized the habituated rule into the new stream had to rely on rule learning to do so. In every experiment, most of the infants lingered longer at the stream unfamiliar to them, confirming the authors' expectations that rule learning is a separate tool from statistical learning, and is just as important in language acquisition. It is important to clarify that the results do not exclude statistical learning or other strategies from an infant's repertoire of learning mechanisms, but only demonstrates that rule learning is a separate and equally important tool in the learning of languages.

The considered study held in 1999 was a milestone in the investigation of rule-learning for all following scientists. At that point, rule learning was thought to be a process innate to humans and particularly designed for language acquisition (Marcus et al., 1999, 2007). However, this finding was not widely accepted in the scientific community and several experimentalists produced evidence contrary to this belief. Part of the opposing movement were Hermann Bulf, Viola Brenna, Eloisa Valenza, Scott Johnson and Chiara Turati, all authors of a study that investigated rule-learning when the presented stimuli were faces. The selection of faces as the presented stimuli was, from the start, a strategic choice. Other findings had already safely established that when the subjects were familiar with the nature of the stimulus (i.e. language, shapes, etc.), their performance in the rule-learning tasks increased, showing a positive correlation between the two. Therefore, faces, being one of the most available stimuli to younglings, were the selected stimuli to present the infants with. During the experimentation, seventy-one caucasian 7-month-olds were considered for the overall results, half of them having been assigned to the ABB condition and the other half to the ABA. The procedure involved using eight face identities for habituation and another four for testing. All the habituation sequences were created with randomly combined faces, presented one after the other on a computer screen (**Fig. 2**). Both the habituation and test phase made use of an infant-controlled procedure, where testing began with a cartoon animated image to capture the subject's attention. Habituation ended once the infant's looking time met a criterion formerly agreed upon, in this case, of a time equal to or less than 50% of the total looking time from the first three trials. Then, the test phase was set in motion with novel stimuli for each sequence - and looking times were recorded.

Just as predicted, the infants' familiarity with the type of stimulus modulated their rule-learning

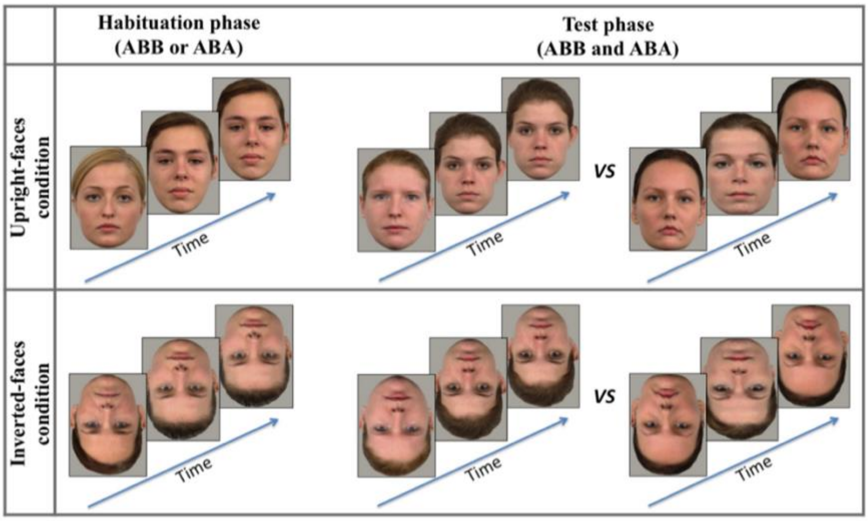

FIG. 2 Examples of the stimuli used during the habituation and test phases.

capacities. Therefore, infants habituated to upright faces exhibited a preference for novel sequences, suggesting rule extraction, while those habituated to inverted faces did not show discrimination between novel and familiar sequences. The study also compares results with previous research involving unfamiliar visual stimuli, emphasizing the impact of perceptual complexity on infants' rule learning. These findings support the idea that perceptual experience plays a crucial role in infants' rule-learning abilities, suggesting a domain-general mechanism rather than one specific to language acquisition.

6. Autism Spectrum Disorder (ASD)

Autism Spectrum Disorder (ASD) is a complex neurodevelopmental condition characterized by persistent challenges in social interaction, communication, and behavior. Usually already visible during early childhood, the disorder is incredibly heterogeneous and so the spectrum ranges from very mild to severe cases (Lord et al., 2018). Even if associated with a strong genetic component, ASD's phenotype is also influenced by environmental risk factors such as advanced maternal and/or paternal age. Throughout this chapter, the multifaceted aspects of ASD will be explored, focusing on three main topics (i, ii, iii):

i. the diagnosis criteria,
ii. the implicit learning implications, and
iii. the educational considerations.

Drawing upon a myriad of scientific publications, this chapter aims to provide a comprehensive understanding of ASD from a multidisciplinary approach – gathering insights from different fields of psychology.

6.1. Diagnosis Criteria

The diagnosis of ASD involves a careful evaluation of behavioral patterns and developmental history. As outlined by the 5th Edition of the American Psychiatric Association's Diagnostic and Statistical Manual (DSM-5), there are two main domains of deficits for this disorder (i, ii):

i. social communication and interaction, and
   a. social-emotional reciprocity deficits,
   b. non-verbal communication deficits, and
   c. relationship deficits.
ii. restricted, repetitive behaviors.
   a. stereotyped actions,
   b. inflexibility to change,
   c. restricted and fixated interests, and
   d. dysfunctional reactivity to sensory input.

Each domain is then fourthly specified, and for anyone to meet the parameters for diagnosis they must present all three of type (i) deficits, and at least two of type (ii) deficits. An additional criterion is that symptoms must have been observed during early development, and they must cause meaningful debilitation in some important area of life. It is also pertinent to mention that, since ASD has a high comorbidity rate with intellectual disability, below-average social communication scores result on the combined diagnoses of ASD and intellectual developmental disorder.

Social communication and interaction deficits can appear in numerous settings and therefore can be extremely impairing to a person. In the case of ASD, these impairments take the form of three scopes. The first of them, or the social-emotional reciprocity scope, calls for a problem in interpersonal engagement. Say Jane, a student with ASD, encounters a classmate in the street. She might not be able to approach this person or to hold a conversation with them. As the name suggests, she might be unable to respond to her classmates appropriately. The second scope, that of non-verbal communication difficulties, refers to failures in the assimilation of verbal and non-verbal correspondence. Still borrowing from the previous example, Jane would not fittingly include body or facial expression to the interaction, she might also have troubles holing eye contact. The last of the three scopes alludes to deficits in understanding the nature of relationships themselves, part of which includes addressing issues related to both cultivating and sustaining relationships. For Jane, it would mean that she might have a hard time making friends or adapting her behavior as a response to setting changes.

The other symptomatic domain focuses on patterns of behavior that are commonly restricted and/or repetitive. In this general sphere, there are four types of deficits: stereotyped actions, inflexibility to change, restricted and fixated interests, and an atypical sensitivity to sensory input. The first of them could be shown through both motor behavior and speech. This output could take the shape of repetitive motor habits, for example, or of speech and of placing objects a certain way (e.g. in a circle, each 3cm from the other). The second type of deficiency takes the form of a rigid adherence to all that is familiar – so, for example, the creation of verbal and non-verbal behavioral routines. The third type of deficits manifests as an abnormal attachment to particular topics of interest, typically familiar objects. The last of the scopes, which addresses the anomalous reaction to sensory stimuli, can be shown as particularly negative responses to sounds, textures, or tastes. It can also be shown, rather than as a hyper-reactivity to sensory input, as a hypo-reactivity to it, so an unexpected indifference to pain or temperature.

While the diagnostic criteria for ASD are well-defined, the scientific community has not fully grasped the intricacies of the condition. Part of that is because, despite its notable genetic link, all ASD diagnoses rely solely on behavioral aspects. This is not due to it being exclusively a behavioral condition, but rather because specific biomarkers for the disorder have not been identified yet (Schipul et al., 2012). Since it is a complex disorder, thought to involve a combination of genetic, neurological, and environmental factors, pinpointing specific molecular indicators is not a simple task. Another important aspect of the condition is altered brain development and neural arrangement. Unlike previously thought by scholars, ASD is more an impairment of under-connectivity in the frontal and posterior cortices than a localized dysfunction in the brain – and it seems that early brain reorganization is responsible for these differences. Nowadays, with the help of neuroimaging techniques, it is known that autistic people most likely have increased brain volume growth during early development (Schipul et al., 2012). These screening techniques, even if not sufficient to diagnose ASD by themselves, probably explain part of ASD's altered sensitivity to the environment and learning styles.

In addition, the diagnostic landscape for Autism Spectrum Disorder (ASD) involves a variety of tools and assessments. The Modified Checklist for Autism in Toddlers (M-CHAT) and the Communication and Symbolic Behavior Scales (CSBS) serve as survey methods, usually introduced for caregivers to understand if further consultation is needed. For a more comprehensive evaluation, standardized diagnostic instruments such as the Screening Tool for Autism in Toddlers and Young Children (STAT) and the extensively researched Autism Diagnostic Observation Schedule (ADOS) are available. These instruments offer a thorough observation-based approach, accommodating different language levels and ages from early childhood to adulthood. The diverse array of diagnostic tools underscores the complexity of ASD, reflecting the need for a multifaceted approach to capture the broad spectrum of behaviors and characteristics associated with this neurodevelopmental condition.

Before transitioning to the exploration of implicit learning in ASD children, it is crucial to highlight a few concluding points in this section. Firstly, it's essential to clarify that reported symptoms for diagnosis can be based on current experiences or historical descriptions. This means that adults who may not currently meet diagnostic criteria but recognize past alignment with such criteria are still eligible for diagnosis. Additionally, it's noteworthy that symptomatic experiences vary in severity, with some individuals experiencing significantly more debilitation than others. These differences emphasize the need for personalized interventions when dealing with ASD, always tailored to each individual's needs.

6.2. Implicit learning implications

In this subchapter, the emphasis returns to the exploration of implicit learning mechanisms. However, the objective now is not to analyze it in the context of typical development, but instead in the relevant scenario for ASD children. As was the case for the typical development discussion, two main cognitive processes shall be brought up (i, ii):

i. statistical learning, and
ii. rule learning.

To comprehend the present literature on this section's topic, it is essential to recognize that numerous studies have challenged the notion of implicit learning deficits as a fundamental aspect of ASD. Two specific studies have been chosen to exemplify this line of reasoning – "Implicit learning in individuals with autism spectrum disorders: a meta-analysis" and "Statistical learning as a window into developmental disabilities". In addition to these, two other articles that support the opposing view will also be analyzed. These latter ones are "Dissociation Between Linguistic and Nonlinguistic Statistical Learning in Children with Autism" and "Rule learning in autism: the role of reward type and social context".

The first study mentioned, conducted by Foti et al. in 2014, was a meta-analysis that concentrated on understanding learning challenges within the autistic population. Originating from the hypothesis of a potential link between ASD and implicit learning deficits, the researchers aimed to shed light on the characteristic social dysfunctions of ASD. For that reason, an ensemble of 11 studies and a total of 407 autistic individuals were considered, not to mention other typically developing comparison participants. The variables employed in the group of studies were four: serial reaction times (SRT), alternating serial reaction time (ASRT), pursuit rotor (PR), and contextual cueing (CC) tasks. Contrary to the initial hypothesis, the results of the meta-analysis revealed that individuals with ASDs did not exhibit significant differences across any of the considered tasks. However, it is crucial to critically assess the implications of these results. Are the studies presented in this meta-analysis sufficient to definitively conclude that individuals with ASDs do not experience implicit learning deficits, or is further investigation warranted? The debate surrounding the conclusiveness of these findings prompts a thoughtful consideration of the broader implications for understanding learning difficulties in ASDs.

The second study under consideration, conducted by Jenny Saffran in 2018, aimed to explore differences in statistical learning for children with intellectual and developmental disabilities (IDD). While literature reveals significant individual variation in statistical learning abilities, studies including children with Specific Language Impairment (SLI) and developmental dyslexia establish correlations between deficits in statistical learning tasks and language challenges. However, a notable departure from this pattern surfaces when examining autism spectrum disorders (ASD). Individuals with ASD exhibit proficiency in statistical learning tasks, challenging assumptions about uniform learning difficulties within IDD conditions. This prompts the question: do individuals with ASD and typically developing individuals inherently utilize the same implicit learning mechanisms, or is it more plausible that their similar performance stems from shared outcomes rather than identical cognitive tools? To delve deeper into this inquiry, it is imperative to explore additional studies that may unveil distinctions in implicit learning within the ASD context.

The third study in question, conducted by Hu et al. and published in 2023, is the first of the examined papers to indicate some sort of learning divergence for ASD. The authors, initially driven by a desire to better understand the link between statistical learning (SL) and language, compared SL profiles in children aged 6 to 12 across modalities and domains. To achieve this, the study incorporated four distinct stimulus types (2 modalities x 2 domains), comprising: auditory linguistic (syllable), auditory non-linguistic (tone), visual linguistic (letter), and visual non-linguistic (image). Then, considering both reaction time and accuracy, each performance in the SL tasks was assessed. At this point, the hypothesis was that individual language skills would be associated with statistical learning performance in linguistic tasks, but not in non-linguistic ones (Hu et al., 2023). The methodology applied in the study included 55 children with ASD roughly between 6 to 12 years old, plus other 50 age-matched typically developing children. Firstly, the autistic children's language skills were rated by their parents, with ratings ranging from significantly below to above age language levels. Out of all ASD participants, twenty were at or above age level, and twenty-six were slightly or significantly-below age level. The parental assessment was additionally supported by the Redmond Sentence Recall Task for a part of the participants (33/55 ASD children and 34/50 typically developing children), which confirmed the credibility of the parents' judgement. Then, for each of the SL tasks, a familiarization phase was conducted. Those consisted of target detection tasks, which were followed straight away by the test phase. During the first phase, a continuous stream of 4 triplets was shown, with the nature of the triplets changing according to modality and domain of investigation, all lasting for about 5 minutes. The second phase, shown immediately after the familiarization phase, was composed of 2AFC (two-alternative forced choice) type-questions. This involves presenting participants with two options and requiring them to choose one of them, therefore assessing discrimination or recognition abilities. One of the options was the target one, taken out of the pool of triplets the participant was shown in the first phase, and the other option was the foil triplet, new to the participant (**Fig. 3**). Overall, the ASD participants results' showed weaknesses in linguistic activities (syllable and letter tasks), displaying slower learning and poorer pattern retrieval. Following the authors' expectations, their performance in nonlinguistic statistical learning tasks (image and tone) mirrored that of typically developing peers.

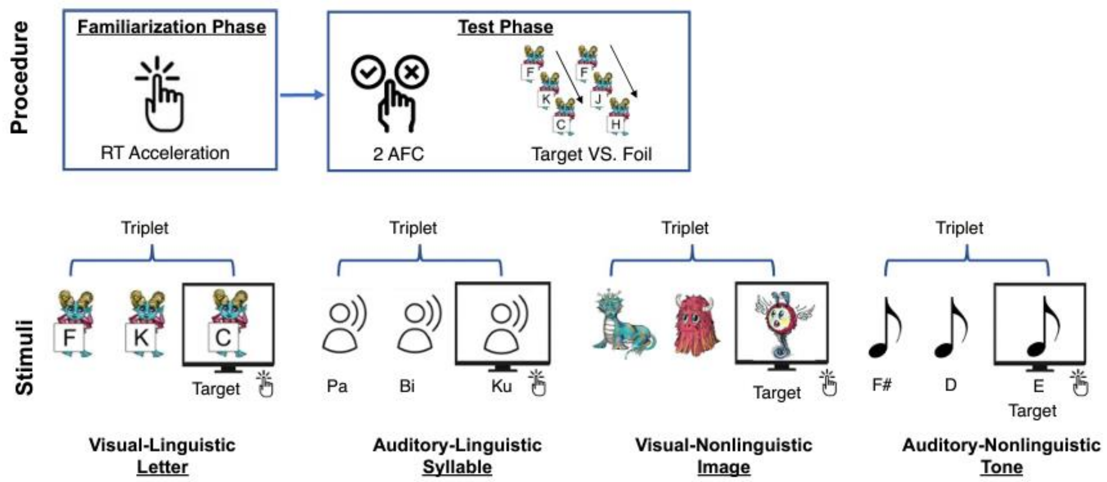

Fig. 3 Overall procedure (top row) and the stimuli examples (bottom row) of the SL tasks

These findings support the idea that statistical learning operates independently across modalities, and most likely alongside a more domain-general learning system (Hu et al., 2023). Another relevant result is that older autistic children exhibited more evident linguistic statistical learning difficulties when compared to their younger peers. According to some literature, statistical learning is a process that happens in steps, and it is yet unclear which of these are disrupted for ASD individuals, or why it happens to be almost exclusively linked to the linguistic domain. It is possible that the first step, that of encoding each stimulus, is disrupted for ASD children due to an abnormal reactivity to speech when compared to typically developing children. In a general analysis, the study – even though having accomplished its main goals - acknowledges the need for further investigations, especially in understanding the relationship between language experience and SL development.

In the 2013 study by Jones et al., the thesis discussion transitions from the statistical learning framework to that of rule learning (RL). Given the fundamental role of rule learning abilities in acquiring linguistic and social skills, both of which pose core challenges for individuals with autism spectrum disorder, it is evident that a connection between RL and ASD can be reasonably posited. One of the fundamental brick-blocks in the construction of this article was, in fact, a question: why do autistic children have difficulties in learning and applying rules? The main hypothesis demonstrated by the authors is that ASD individuals might not learn the same way as typically developing people when rewards are inserted into the equation. For each developmental period, particular types of rewards are more effective for the success of RL tasks – and the more abstract or delayed the reward, the more it calls for a better maturation of the prefrontal cortex. When combining this hypothesis with the idea that RL might be more impaired in social contexts, the proposal of the study is born: to investigate the longitudinal development of rule-learning skills in ASD, especially when in relation both to reward type and to social context. For the achievement of this aim, data were taken from another longitudinal study that tested ASD children when they were 4, 6 and 9 years old. In addition to these data, the delayed non-matching to sample (DNMS) task was applied. This task involves presenting individuals with a sample stimulus, allowing them to memorize or learn it. After a delay period, the individual is then presented with a choice between the familiar (matching) stimulus and a new (non-matching) stimulus. The task requires the individual to choose the non-matching stimulus, indicating their ability to remember the original stimulus and recognize it as different from the new one. It is often employed in research to study cognitive processes and assess cognitive impairments in various populations, including animals and, in the case of this particular study, high and low-functioning ASD individuals. The inclusion of social stimuli also further specifies the task's results, allowing the assessment of the participants' performance across domains (social vs. non-social). The study, being a complex and extensive analysis, included two experiments. The first of them focused on the investigation of age-related changes in rule-learning abilities, and more specifically the impact of reward type during these tasks. At this point, previous literature had already found that even though 4-year-old ASD children performed similarly to typically developed age-matched children, when they reached 5 to 7 years old, their performance collapsed in comparison to the age-matched group. Wanting to explore this developmental discrepancy further, Jones et al. applied the DNMS task in 6-year-old children originally tested at 4 and examined the longitudinal changes. For this experiment, the comparison group was that of children with developmental delay (DD). Though it was expected that the ASD group would show increased deficits from 4 to 6 years old when in comparison to the DD, no such evidence was found. However, the ASD group did have less performance stability, which implies greater challenges in rule-learning tasks for autistic children, especially those in the low-functioning part of the spectrum. Another relevant result is that rewarding ASD children with contingent verbal praise facilitated rule-learning, particularly more than when the reward is physical (**Fig. 4**). Rule-learning ability was also significantly correlated to socialization impairments, indicating a close connection between the capacity to acquire rules and challenges in social development among individuals with ASD. This connection, a great part of the general scheme of the study, will be the main topic for the second experiment conducted for the research, called "rule-learning in the social domain". In this last experiment, two different versions of the DNMS task were administered. One of them engaged objects as the stimuli (non-social), and the other, faces (social). Children underwent testing at the age of 9, a stage where prior research (Loveland et al., 2008) suggested no notable rule learning impairment with non-social stimuli. The primary hypothesis suggests that if children with ASD confront greater challenges in

deducing rules from social stimuli, their performance on DNMS–Object should resemble that

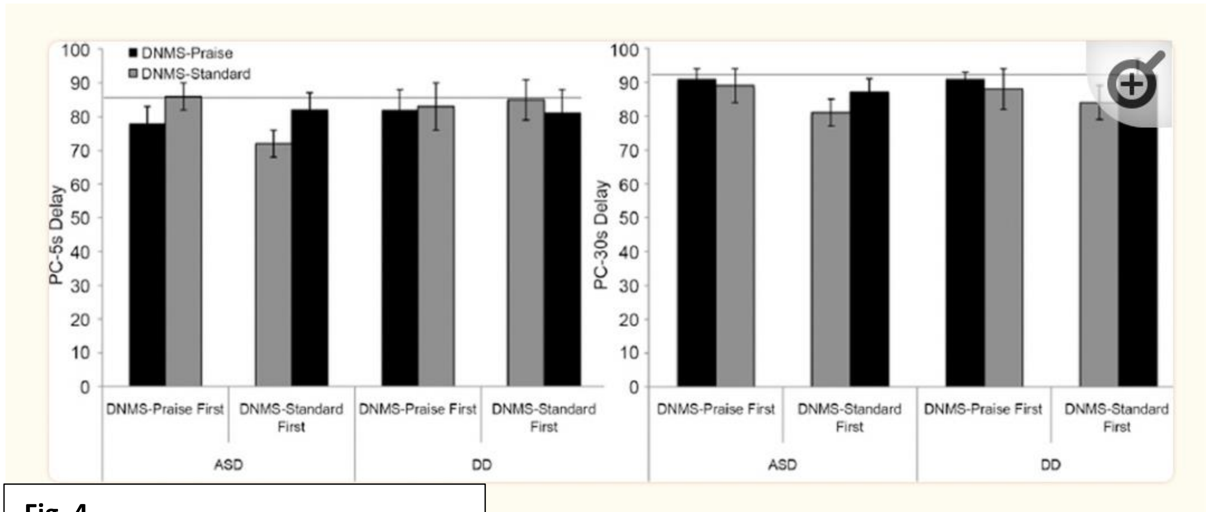

Fig. 4

of the DD group, but they are expected to exhibit lower performance on DNMS–Face. Accordingly, results showed that rule-learning ability was poorer for social rather than non-social stimuli only for the ASD group (**Fig. 5**). It is important to clarify that, being a longitudinal analysis, the study presents significant limitations. Even though the DNMS task is applied across ages and individual differences, modifications must be made in order to assure that each age group completes an appropriate version of the test. However, said necessary changes can affect the comparability of results between age-points. Replicability of the study is fundamental to assure the validity of results.

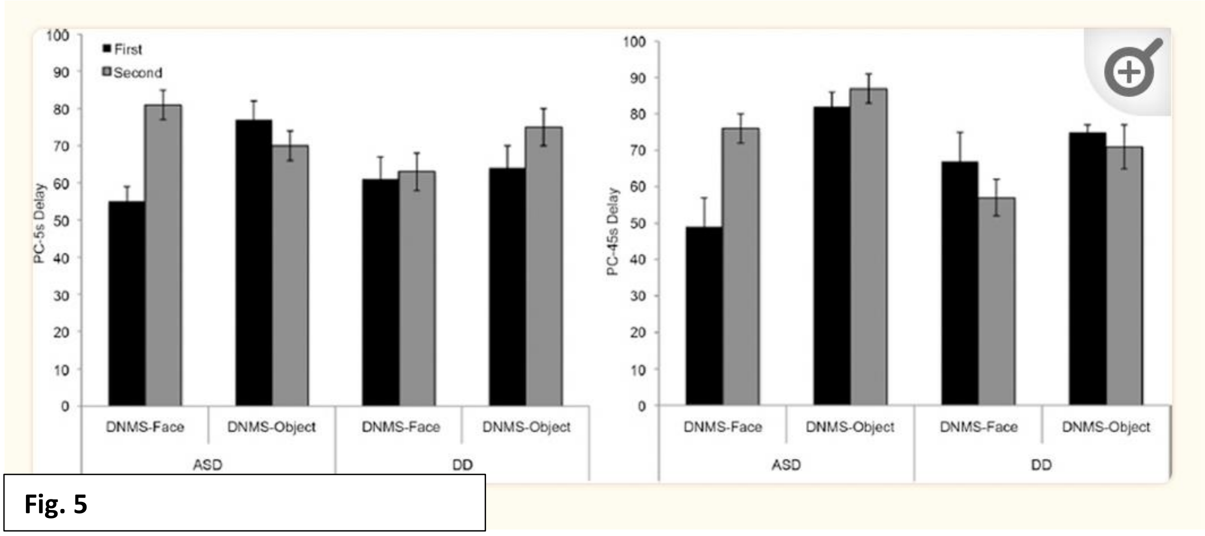

Fig. 5

6.3. Educational considerations

As highlighted in preceding chapters, ASD exhibits significant heterogeneity, affecting individuals diversely and with varying degrees of intensity. Addressing this diversity poses a challenge for institutions seeking to implement beneficial strategies – and scientific literature behind these strategies is fundamental for successful interventions. In this chapter, these approaches will be considered, including those from already examined literature and those from additional work in the field.

To explore these interventions in greater detail, Myers and Johnson's 2007 insights into managing ASD shall be considered. However, in the context of this thesis, since the focus is on the educational setting rather than the clinical one, only the most scientifically relevant interventions will be mentioned. Among these are applied behavior analysis[1], speech and

[1] applied behavior analysis – reinforcement-based treatment typically used for the development of skills and management of self-harm habits.

language therapy[2], occupational therapy[3], sensory integration therapy[4], and psychopharmacological treatments[5]. It is essential to clarify that when addressing the diagnosis of ASD, early recognition is crucial for its successful management. Even though early identification does not mean the disorder can be cured, it does mean that the autistic child has better chances of improving their quality of life and coping with ASD's core features. The education of affected children and those closest to them is equally important.

Moreover, when it comes to the lives of people with ASD, certain intervention approaches have proven to be more effective than others. Focusing on the involvement of family, teachers, and direct providers has proven particularly impactful (Lord et al., 2018), leading to higher success rates for interventions. Beyond identifying the most impactful contributors to interventions – namely, family, teachers, and direct providers – it is equally crucial to recognize the timing of these actions. Anticipating transitional periods in the lives of individuals with ASD, who often struggle with change, can provide valuable support.

Now, shifting the focus toward the educational sector, a question that is both philosophical and practical arises. Should ASD kids be integrated into regular curriculum classrooms, or are "special needs" schools more adequate? The philosophy of the question rests on the field of ethics: why, when inclusion is a civil right, would there be segregated schools for autistic children? The other part of the question's meaning is regarding the actual efficacy of teaching in each setting: are specialized schools necessarily better equipped for managing autistic children? The review written by Harrower and Dunlap seems to take a position. Firstly, the authors suggest that ASD children should benefit from their civil rights and be included in regular education programs. Nonetheless, their inclusion cannot mean the children are left to deal with system that does not fit them, with no educational support. Several effective strategies for the education of atypical development can be implemented in schools, and these are the emphasis of this subchapter.

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[2] speech and language therapy – focus on the development of the child's communicational and social skills.
[3] occupational therapy – therapeutic activities for the construction of adaptive behaviors and increase independence.
[4] sensory integration therapy - therapeutic approach focused on helping children process and respond to sensory information more effectively.
[5] psychopharmacological treatments – usually accompanies other interventions.

The few first strategies to be mentioned belong to the group of antecedent procedures. The name "antecedent" draws light to the very nature of the interventions: they are proactive, so they are implemented before the challenging behavior even occurs. Of these, three are particularly important for teaching ASD kids:

i. priming,
ii. prompt delivery, and
iii. picture scheduling.

Priming, the first of them, aims to expose the children to possibly challenging activities before they are expected to engage in them (Harrower and Dunlap, 2001). This strategy successfully allows the child not only to have individual instruction and support but also to better participate in group activities. The second of the interventions, namely prompt delivery, consists of aiding students with cues during the instructional routine. This helps the kids transition between activities – with the objective that one day they might do so independently. The last antecedent strategy to be discussed is that of picture schedules. The non-verbal aspect of this tool guides the neurodivergent students toward a more predictable – and therefore comfortable – routine. This way, they are generally more equipped to transition activities by themselves.

Now, instead of antecedent contingencies, the focus is on delayed ones. A typical behavioral problem within the spectrum – one that is not addressed by the strategies already discussed – is the necessity of supervision. Often, autistic kids can maintain appropriate behavior only when they are being supervised, a situation that proves itself challenging when one of the main goals of education is to increase students' independent academic functioning. Delayed or unpredictable contingencies can be a tool to sustain the behavioral gains and also to unsupervised scenarios. If an ASD student is dependent on the supervisor's feedback, for example, consistently delayed assessment by the instructor can help with the student's independence.

Another relevant group of strategies that also help with independence are those that are managed by the children themselves. For this, the kids must not only be able to discriminate between suitable and unsuitable behavior, but also be more self-aware when evaluating and monitoring their own conduct. Then, when they reach the desired behavior, they introduce reinforcements. This particular ensemble of strategies has been shown to greatly increase classroom independence, and consequently increase social interaction and inclusion.

The last of the strategies to be discussed are of peer-mediated nature. These strategies emphasize the social challenges of ASD and target the increase in participation during class. Because these interventions are mediated by typically developing counterparts, less one-on-one time is needed between the teacher and the autistic child - and therefore a more independent behavior can be learned. Three interventions are of particular interest:

i. peer tutoring,
ii. peer support, and
iii. cooperative learning.

Peer tutoring consists of pairing two students (one with ASD and a typically developing colleague) to work together in targeted activities. This strategy can increase desirable behavior and social communication in and out of class. The second strategy consists of utilizing peer support. Its goal is essentially the same as peer-tutoring, but it is not organized as one-on-one contact, and it is a bit more centered on increasing social interaction. Finally, cooperative learning is an approach that aims to increase both academic performance and social interaction. Peer-related interventions are, overall, a great option for more inclusive schools. That being said, they alone are unable to provide sufficient support to atypically developed kids.

7. Conclusions

So, having in mind all considerations brought by the present thesis, a main question still remains: are implicit learning deficits at least partly responsible for some of ASD' core features? Some of the research analyzed postulated that there are no significant differences between ASD and typically developing peers when it comes to implicit learning performance. Others, however, provided results that leave a gap that still has not been sufficiently supported by scientific evidence.

In the scope of statistical learning (SL), analyzed literature established that the mechanism is active from early infancy and plays a crucial role in the newborn's representation of the world. Initially, when comparing performances, no clear differences between normally developing and ASD children were found – except when the tasks included linguistic processing. A different result for verbal activities suggests that SL could work independently from one modality to another, with the linguistic modality posing problems to autistic kids. It is yet unknown why linguistic tasks are the problematic ones, and further scientific exploration is needed to understand which SL underlying mechanisms are dysfunctional for this population. Hu et al. (year) postulated that, because of an abnormal reactivity to speech, ASD children could have a deficiency in the encoding of speech stimuli. This postulation, however, is not final nor confirmed and therefore does not exclude the necessity for more studies in the field.

Rule learning (RL), the other implicit mechanism extensively discussed by the present thesis, is also of great importance to a child's understanding of the world. It consists of the identification of rule-like patterns and the subsequent application of the learned rules to other scenarios – an essential part of both language acquisition and socialization. When comparing typical to ASD performance, social stimuli were once again found to be the most challenging for autistic kids – but the explanations are still missing. Not only is there a need for the replication and confirmation of already existing literature, but also for the creation of more experimental designs that could help shed some light on the subject.

Since it is clear that ASD individuals cope with learning disabilities, it is unquestionable that schools must adapt their tools to fit also those who are atypically developed. For this reason, some of the most relevant interventions in schools such as priming, picture scheduling, and peer tutoring should be introduced in traditional classrooms. Another matter in this subject is the link between implicit learning and institutions. In traditional classrooms, explicit learning is often the main – if not only – method of teaching. However, if it has been posited that implicit learning deficits pose at least some influence on ASD's learning profile, why not introduce complementary implicit learning activities to bridge the difference between regular students and autistic students? Once again, more publications in the field are pivotal for a better understanding of how schools can help with autistic kids' learning curves.

Overall, the evidence brought to light by this thesis seems to link implicit learning to some of the learning disabilities of ASD individuals. Particularly, the first domain of symptoms which is that of social communication and interaction. The mechanisms through which they are connected, though, remain unclear. It seems that, for starters, a stronger conception of implicit learning must be acknowledged. If the processes through which implicit learning occurs (including cognitive models of its functioning) are solid, then the link to ASD's learning disabilities will also become clearer.

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