Journal of Experimental Psychology: General

Category Learning in Autism: Are Some Situations Better Than Others?

Anne-Marie Nader, Domenico Tullo, Valérie Bouchard, Janie Degré-Pelletier, Armando Bertone, Michelle Dawson, and Isabelle Soulières

Online First Publication, September 16, 2021. http://dx.doi.org/10.1037/xge0001092

CITATION

Nader, A.-M., Tullo, D., Bouchard, V., Degré-Pelletier, J., Bertone, A., Dawson, M., & Soulières, I. (2021, September 16). Category Learning in Autism: Are Some Situations Better Than Others?. *Journal of Experimental Psychology: General*. Advance online publication. http://dx.doi.org/10.1037/xge0001092

AMERICAN PSYCHOLOGICAL ASSOCIATION

Journal of Experimental Psychology: General

© 2021 American Psychological Association
ISSN: 0096-3445

https://doi.org/10.1037/xge0001092

Category Learning in Autism: Are Some Situations Better Than Others?

Anne-Marie Nader[1], Domenico Tullo[2], Valérie Bouchard[1], Janie Degré-Pelletier[1], Armando Bertone[2, 3], Michelle Dawson[3], and Isabelle Soulières[1, 3]

[1] Department of Psychology, University of Quebec in Montreal
[2] Department of Educational and Counselling Psychology, McGill University
[3] Autism Research Group, CIUSSS du Nord de l'île de Montréal, Montreal, Canada

Autism is diagnosed according to atypical social-communication and repetitive behaviors. However, autistic individuals are also distinctive in the high variability of specific abilities such as learning. Having been characterized as experiencing great difficulty with learning, autistics have also been reported to learn spontaneously in exceptional ways. These contrasting accounts suggest that some situations may be better than others for learning in autism. We tested this possibility using a probabilistic category learning task with four learning situations differing either in feedback intensity or information presentation. Two learning situations compared high- versus low-intensity feedback, while two other learning situations without external feedback compared isolated sequentially presented information versus arrays of simultaneously presented information. We assessed the categorization and generalization performance of 54 autistic and 52 age-matched typical school-age children after they learned in different situations. We found that children in both groups were able to learn and generalize novel probabilistic categories in all four learning situations. However, across and within groups, autistic children were advantaged by simultaneously presented information while typical children were advantaged by high-intensity feedback when learning. These findings question some common aspects of autism interventions (e.g., frequent intense feedback, minimized simplified information), and underline the importance of improving our current understanding of how and when autistics learn optimally.

Keywords: autism, learning, perception, feedback, cognition

This document is copyrighted by the American Psychological Association or one of its allied publishers.
Content may be shared at no cost, but any requests to reuse this content in part or whole must go through the American Psychological Association.

Preliminary results from this study have been presented at the annual conference of the International Society for Autism Research and of the International Neuropsychological Society.

Anne-Marie Nader https://orcid.org/0000-0001-6389-6885
Isabelle Soulières https://orcid.org/0000-0002-0875-4101

Anne-Marie Nader, Michelle Dawson, Domenico Tullo, Armando Bertone, and Isabelle Soulières developed the study concept and contributed to the study design. Testing, data collection, data analysis, and interpretation were performed by Anne-Marie Nader, Janie Degré-Pelletier, and Valérie Bouchard, under the supervision of Isabelle Soulières. Anne-Marie Nader and Michelle Dawson drafted the article and Armando Bertone and Isabelle Soulières provided critical revisions. All authors approved the final version of the article for submission.

This study was presented as part of PhD dissertation of Anne-Marie Nader. This work was supported by a career Award to Isabelle Soulières from Fonds de recherche du Québec–Santé (FRQS; Quebec's Health Research Fund) and a doctoral Award from FRQS to Anne-Marie Nader. These funding sources had no involvement in the study design, the collection, analysis and interpretation of data and in article writing. We gratefully thank the participants, their families, school administrators, and staff for their time and commitment for this research. We also thank Eliane Danis, Alexandra Tremblay, Etienne Côté, and Simon Lafrance for assistance. The authors declare no conflict of interest.

Correspondence concerning this article should be addressed to Isabelle Soulières, Department of Psychology, University of Quebec in Montreal, C.P. 8888 Succursale Centre-Ville, Montreal, QC H3C 3P8, Canada. Email: soulieres.isabelle@uqam.ca

Autism is a neurodevelopmental disability whose diagnostic criteria combine atypical social communication with restricted and repetitive behaviours (American Psychiatric Association [APA], 2013). High variance in outcomes across the life span is characteristic of autism (Cowen, 2011), as is high apparent variance in specific abilities such as learning. The literature has provided disparate views on questions regarding how and how well autistics learn (Dawson et al., 2008, for an overview). For example, typical children's automatic and constant learning from relevant information in their environment has been contrasted with autistic children's lack of motivation or ability to do so (Koegel et al., 2016; Lovaas, 2003; Lovaas & Smith, 1988; Smith, 2001). Autistic children have in addition been portrayed as requiring comprehensive support to mitigate multiple learning impairments stemming from deficits in executive functioning, sensory processing, and complex information processing (Cannon et al., 2011; Kenworthy et al., 2014). Nevertheless, the literature also documents spontaneous and sometimes outstanding manifestations of learning that are distinctive or prevalent in autism, including savant abilities and hyperlexia (Heaton & Wallace, 2004; Kissine & Geelhand, 2019; Mottron et al., 2009; Ostrolenk et al., 2017). Such marked contrasts across accounts of learning in autism are intriguing and of clear importance for autistic outcomes, yet this heterogeneity in autistic learning remains understudied and unexplained. As a result, existing developmental, behavioral, and educational approaches to autism lack theoretical grounding regarding how, when, and why autistics learn well or badly.

An influential view of learning in autism, in both research and practice, has been that autistics are unable to spontaneously learn

This document is copyrighted by the American Psychological Association or one of its allied publishers.
Content may be shared at no cost, but any requests to reuse this content in part or whole must go through the American Psychological Association.

from presented information, and unable to go beyond the rigid use of simple rules to learn complex regularities and probabilities (Eigsti & Mayo, 2011). Only recently has this view been called into question by studies using implicit learning tasks and which failed to find predicted learning deficits in autistic children, adolescents, and/or adults, across an array of tasks (for example, artificial grammar, serial reaction time, contextual cuing, probabilistic classification; Foti et al., 2015; Obeid et al., 2016; Zwart et al., 2019, for systematic reviews). There may nevertheless be situations in which autistics have difficulty learning (e.g., Crawley et al., 2019; Scott-Van Zeeland, Dapretto, et al., 2010), as well as situations where their learning is enhanced compared to typical controls (e.g., Roser et al., 2015). While autistics have demonstrated an absence of typical neural activation during language-based implicit learning (word segmentation; Scott-Van Zeeland, McNealy, et al., 2010), they have also shown typical learning on this task (Haebig et al., 2017; Mayo & Eigsti, 2012; Saffran, 2018, for a review). Therefore, current evidence suggests that although autistics can spontaneously learn complex regularities or probabilities, as exemplified by implicit learning tasks, they may use atypical cognitive processes to do so, resulting in variable outcomes that to date remain unexplained (Cannon et al., 2021).

The overlapping issue of how or whether autistics form categories to structure information dates to the seminal work of Hermelin and O'Connor (1967) who demonstrated autistic children to be less dependent on probabilities and categories when recalling words. However, when directly assessed, autistic children were able to demonstrate typical semantic category organization (Tager-Flusberg, 1985a, 1985b; Ungerer & Sigman, 1987). More nuanced tests of categorization strategies in autism have followed that involved rules, exemplars, prototypes, and/or generalization across a range of stimuli (e.g., dot patterns, artificial animals, face images). Results have been mixed (e.g., reduced prototype use in Church et al., 2010; but not in Molesworth et al., 2005), suggesting that while category learning may not be typical in autism with respect to strategy, speed of learning, and range of information used, autistics are nonetheless able to learn complex category structures in some situations (Soulières et al., 2011). This heterogeneous performance in category learning and generalization in autism remains inadequately explained (Mercado et al., 2015, 2020). It may stem at least in part from as of yet undefined situations that either advantage or disadvantage autistic learning, and which differ from their counterparts for typical learning. Specifically, current discrepancies in findings across existing studies may originate from overlooked differences in the way tasks are designed with respect to how and how much information is presented to participants. If relatively minor differences in learning situations produce differences in autistic (vs. typical) learning even within a single task, this could in turn lead to progress in explaining the apparently high variance in learning abilities reported across the autism literature. Two such differences in learning situations, within a probabilistic category learning task, are central to this study: the presence and nature of trial by-trial feedback; and the manner with which information is presented to participants.

Feedback, the first difference, is a feature of learning phases in probabilistic category learning tasks (Brown et al., 2010) in which participants must start by guessing which stimuli belong in which category and adapt their answer according to the feedback provided after each trial. Trial-by-trial feedback may be limited to elements that are strictly informative about the category structure itself, as in a simple stimulus tone/word indicating a correct or incorrect response, and a running count of responses. Feedback may also encompass elements that are not limited in this way and have intended roles beyond being strictly informative. These may include elaborate and/or superfluous social or nonsocial elements such as smiling faces, praise, or positive sounds and animations that could serve as both informative (e.g., smiling face appears only with correct response) and rewarding to the participant. Such elements add intensity to feedback but do not add to how informative it is, compared to feedback without these elements. Instead, they are relevant to the broad issue of motivation, which spans the related but distinct concepts of reward and reinforcement. Autism research on different types of feedback has concentrated on questions of social versus nonsocial reward value, with findings converging on both being atypical in autism (Baumeister et al., 2020; Clements et al., 2018). Meanwhile, the question of feedback intensity and its effects on learning in autism has been neglected.

As noted above, autistics have long been characterized as lacking the motivation to learn when taught as well as any ability to learn spontaneously (Koegel et al., 2001; Lovaas & Smith, 1988; Smith, 2001). In consequence they are claimed to require intense, elaborate, and frequent feedback (Cooper et al., 2007, 2020; Leaf & McEachin, 1999; Lovaas, 2003); including within the context of "naturalistic" interventions (Schreibman et al., 2015), and extending into school-ages and beyond (e.g., Hume et al., 2021; Mandell et al., 2013; Odom et al., 2010; Wong et al., 2015). Accordingly, learning in autism has been argued to depend on the intensity of noninformative elements of nonsocial and social feedback (including praise; Cannon et al., 2011); with informative-only feedback presumed to be ineffective. Alternatively, autistics could be able to implicitly learn complex regularities or probabilities if presented to them. In this case, intense feedback, including elaborate and superfluous elements which are not additionally informative, may be irrelevant, unnecessary, distracting, and possibly disruptive to learning in autism (Brown et al., 2010; see also Broadbent & Stokes, 2013). Probabilistic category learning tasks can also be performed without the use of any external/explicit feedback (Shohamy et al., 2004). In this case, category membership information is visually integrated into learning phase stimuli (stimulus–category association), which are presented to and passively observed by participants who make no response and thus receive no external/explicit feedback as they learn. If autistics are only motivated or able to learn in the presence of explicit feedback, particularly of high intensity, they should be unable to learn in its complete absence.

How information is presented is the second difference in learning situations central to this study. The feedback-free design in Shohamy et al. (2004) also permits the testing of how information presentation affects category learning in autism. Whereas Shohamy et al. (2004) presented their stimuli one at a time in a sequence during the learning phase, it is also possible to present the stimuli simultaneously in arrays or groups where participants have access to an increased quantity of information at once while learning. Unlike the classical sequential presentation of isolated items, simultaneously presented arrays make available many items from each category at the same time, which may facilitate learning across different levels of information, from entire arrays to specific items to specific features. Influential views of autism, however, posit that autistics are overly selective in attending to limited and irrelevant aspects of complex stimuli (Cannon et al., 2021; Ploog, 2010), comprehensively impaired in complex information processing

This document is copyrighted by the American Psychological Association or one of its allied publishers.
Content may be shared at no cost, but any requests to reuse this content in part or whole must go through the American Psychological Association.

(Williams et al., 2015), and more easily overwhelmed by sensory information (Pellicano & Burr, 2012; Van de Cruys et al., 2014), particularly if it involves complex regularities (Qian & Lipkin, 2011). Consistent with these views, popular approaches to autism feature the breaking down of tasks or objectives into smaller and more simple increments of information that are presented one at a time (e.g., Cooper et al., 2007, 2020; Hume et al., 2021; Maurice et al., 1996; Odom et al., 2010; Smith, 2001; Wong et al., 2015). If these influential views and practices are well-founded, autistic performance should not benefit from, and possibly be hindered by, large quantities of simultaneously presented information during an implicit learning task. Alternatively, a growing body of evidence demonstrates that autistics have an increased, not decreased, perceptual capacity (Remington et al., 2012; Remington & Fairnie, 2017; Remington et al., 2019; Tillmann et al., 2021), which may benefit autistic learning when more, rather than less, information necessary to solve a task is made available at the same time. In the same direction, autistics may particularly benefit from situations allowing them the latitude to process and combine quantities of information across different levels and scales, from small details to large displays (Mottron et al., 2009, 2013). If this alternative view is founded, autistics should be advantaged by the availability of large quantities of simultaneously presented information while they learn complex regularities.

In this study, our aim was to assess the role of feedback intensity (low vs. high) and information presentation (isolated vs. simultaneous) on probabilistic category learning and generalization in autistic children. More specifically, we verified whether the performance of autistic children differed after learning with high versus low feedback intensity, and following isolated versus simultaneous presentation of information. Second, we compared how autistic and typical children performed overall, and on different levels of stimulus-outcome probability, when tested after these four different learning situations.

Method

Participants

School-aged autistic and typical children aged 6–14 years were recruited through the research database of the Autism Specialized Clinic at Rivière-des Prairies Hospital (HRDP; Montreal, Canada), and through four mainstream schools (regular and specialized classes) in a Montreal-area school board. All participants had Wechsler Intelligence Scale for Children-Fourth Edition (WISC-IV) perceptual reasoning index (PRI; Wechsler, 2003) scores of at least 80. The final sample included 106 children, 54 in the autistic and 52 in the typical group, who were alternately assigned to either the feedback or information conditions. Autistic and typical children were matched on age, WISC-IV PRI score, and visual working memory (spatial span backward of the WISC-IV integrated), but subsamples that completed the feedback condition were not sex-matched. See Table 1 for demographic and matching information for the total sample of autistic and typical children, and for the subsamples for each condition. Soulières et al. (2011) obtained an effect size of 1.11 with 16 participants per group using a similar categorization task. Therefore, it is reasonable to expect a large effect size of .80 in our study, which means that a minimum of 23 participants per group yields a power of at least 75% chance to detect an effect if present (Cohen, 1988).

Files for the autistic children were reviewed for diagnostic information. Children in this group had received an autism spectrum diagnosis according to *DSM–5* (APA, 2013) or *DSM–IV–TR* (APA, 2000) criteria; all children were diagnosed by experienced clinicians (child psychiatrist, developmental pediatrician, or psychologist). All diagnostic processes relied on expert interdisciplinary clinical judgment and most of the children were assessed with two gold standard autism diagnostic research instruments:

Table 1
Participant Demographics for the Total Sample and for Each Condition

Participant demographics			
Variables	Autistic	Typical	*p*
	Total sample		
	Autistic (n = 54)	Typical (n = 52)	
Sex	47M: 7F	36M: 16F	.03
Age (years)	10.1 (SD = 2.0; 6−14)	10.0 (SD = 1.8, 6−14)	*ns*
WISC-IV PRI	104.34 (SD = 24.91)	111.31 (SD = 18.97)	*ns*
Spatial span backward (scaled score)	9.90 (SD = 4.16)	10.23 (SD = 5.52)	*ns*
	Feedback condition (low vs. high feedback)		
	Autistic (n = 26)	Typical (n = 28)	
Sex	23M: 3F	18M: 10F	.04
Age (years)	9.4 (SD = 1.9; 6−14)	9.9 (SD = 2.1, 6−14)	*ns*
WISC-IV PRI	103.25 (SD = 25.99)	110.21 (SD = 24.42)	*ns*
Spatial span backward (scaled score)	8.96 (SD = 4.60)	10.40 (SD = 6.09)	*ns*
	Information condition (isolated vs. simultaneous)		
	Autistic (n = 28)	Typical (n = 24)	
Sex	24M: 4F	18M: 6F	*ns*
Age (years)	10.1 (SD = 2.0; 6−14)	10.1 (SD = 1.4; 7−12)	*ns*
WISC-IV PRI	105.36 (SD = 24.30)	112.58 (SD = 9.70)	*ns*
Spatial span backward (scaled score)	10.81 (SD = 3.54)	10.04 (SD = 4.96)	*ns*

Note. WISC-IV = Wechsler Intelligence Scale for Children-Fourth Edition; PRI = perceptual reasoning index. *ns* = nonsignificant. Significance defined by a p of less than 0.05.

This document is copyrighted by the American Psychological Association or one of its allied publishers.
Content may be shared at no cost, but any requests to reuse this content in part or whole must go through the American Psychological Association.

Autism Diagnostic Interview–Revised (ADI-R; Lord et al., 1994) and Autism Diagnostic Observation Schedule–General (ADOS-G; Lord et al., 2000). Among the 54 autistic children, 40 were assessed with both ADI-R and ADOS, and three with ADOS only. For the remaining 11 children, either the information was missing from their file or the diagnosis relied on interdisciplinary clinical judgment. Seventeen percent (9/54) of autistic children also had a formal Attention-Deficit/Hyperactivity Disorder (ADHD) diagnosis, 11% (6/54) had a language disorder (LD) diagnosis, and 6% (3/54) had both ADHD and LD diagnoses.

Typical children were screened for personal or family history of psychiatric, neurological, or developmental conditions, using a semistructured interview conducted with their parents. Of the 56 children originally recruited in the typical group, four were found to be diagnosed with either ADHD or a learning disorder and were excluded from participating, resulting in a final sample of 52 typical children. All typical children had a regular academic background; none were taking medication when tested.

Written informed consent to participate was obtained from parents for all participants; assent was also provided by the children. The study was formally approved by the ethics committee of Rivière-des-Prairies Hospital (Montreal, Canada) and the participating school board (Commission Scolaire des Patriotes, Montérégie, QC, Canada).

Procedure and Conditions

General Procedure and Task Scenario

All participants were tested individually in a quiet office at the hospital clinic or at their school by one of four neuropsychology graduate students experienced in assessing autistic children; testing was completed across three or four sessions depending on the attentional capacities, fatigue, and pace of participants. To optimize child performance, the testing session and schedule were adapted to each child after consulting their teacher or parent. Most of the sessions, for both groups, lasted 40–50 minutes with the constraint that individual tasks were not spread across different sessions.

The first session always included the completion of three WISC-IV subtests (Block Design, Picture Concepts, and Matrix Reasoning) used to derive the PRI score using the French-Canadian version of the WISC-IV and Canadian norms. Following the PRI subtests, the spatial span subtest of the WISC-IV Integrated (Wechsler et al., 2004) was administered. This subtest, similar to the Corsi-block tapping test, was used as a control measure for visuospatial short-term working memory (Spatial span backward, scaled scores with $M = 10$ and $SD = 3$).

Through the following sessions, each child performed two probabilistic categorization tasks adapted from those of Shohamy et al. (2004) and Brown et al. (2010). Children were told that they were selling ice cream in an ice cream shop, and that different customers would come to buy either vanilla or chocolate ice cream cones. Children were asked to learn which customers preferred vanilla or chocolate ice cream most of the time. Each task thus consisted of learning to categorize 14 different "customers" (description of the different characters below) into their most likely outcome (characters preferring chocolate ice cream vs. those preferring vanilla ice cream). Participants were alternately assigned to complete either the two feedback tasks (high vs. low intensity feedback) or the two tasks assessing the role of information presentation (isolated vs. simultaneous information). Therefore, each child completed only two learning tasks. Children completed the learning tasks in a counterbalanced order during two different sessions.

Category Structure and Stimuli

Two distinct category sets were created, one for each task completed by the child. The stimuli in each category set consisted of 14 artificial characters created using either a Mr. Potato Head or Ms. Pumpkin base character, to which different features were added. All base characters had eyes, a nose, white arms, and blue feet. Fourteen (14) characters were then created (defined as characters A through N) by varying the presence (1) or absence (0) of one or more additional features specific to either Mr. Potato Head (hat, moustache, glasses, and bowtie) or Ms. Pumpkin (handbag, hairclip, star pin, and belt). The 14 characters in each set were created following the scheme presented in Table 2, with combinations of features identical to those used by Shohamy et al. (2004). All stimuli were photographed with a digital camera and edited using Photoshop to ensure consistent light, contrast and image size (12 deg in height × 9 deg in width when viewed from 57 cm). The assignment of stimuli set (either Mr. Potato Head or Ms. Pumpkin) to a task and the order of the tasks was counterbalanced across participants, such that half of the children were presented with Mr. Potato Head first, and vice versa (see Figures 1 and 2 for stimuli examples).

There were two outcomes, presented as customer preference, and which were equally probable; vanilla or chocolate ice cream for Mr. Potato Head, and apple or grape juice for Ms. Pumpkin. Each of the 14 characters was probabilistically associated with an outcome. Stimulus–outcome probabilities varied across the stimuli according to six levels, from chance (50%) to high probability (92%), as shown in Table 2 (e.g., character A is associated 89% of the time with the outcome Vanilla and 11% of the time with Chocolate, while character D is associated 22% of the time with Vanilla and 78% of the time with Chocolate). Thus, each feature was associated with an outcome following a fixed probability (note that none of the features predicted the outcome perfectly and certain combinations of features add predictive value). Certain features were more strongly associated with their category. For example, when considered individually (e.g., child chooses vanilla whenever the bowtie is present, otherwise chocolate), Moustache or Bowtie were highly predictive of an outcome and allowed correct classification of 90% of items. In contrast, considering only Hat or Glasses allowed correct classification of 67% of items.

For each of the 14 characters (A to N), three sets of pictures were created; one illustrating only the character without the outcome (no ice cream cone or juice box), one with the presence of the outcome (the character is holding an ice cream cone or a juice box) and finally a generalization set was created for the test phase where each of the 14 stimuli was slightly modified from its original, either with a different color or shape of the four features (e.g., a different shape of moustache).

With exceptions noted below (see simultaneous situation in the Information Presentation Condition section), the stimuli presentation and data collection was controlled using VPixx software (VPixx Technologies; https://vpixx.com/) and a 13-in. Apple MacBook Pro

Table 2
Character Features and Probability Structure of the Four Learning Tasks

Character	Feature 1 Moustache/hairclip	Feature 2 Hat/star pin	Feature 3 Glasses/handbag	Feature 4 Bowtie/belt	Frequency during learning (/200 trials) (Vanilla : Chocolate)	P (Vanilla outcome)
A	0	0	0	1	19 (17 : 2)	.89
B	0	0	1	0	9 (7 : 2)	.78
C	0	0	1	1	26 (24 : 2)	.92
D	0	1	0	0	9 (2 : 7)	.22
E	0	1	0	1	12 (10 : 2)	.83
F	0	1	1	0	6 (3 : 3)	.50
G	0	1	1	1	19 (17 : 2)	.89
H	1	0	0	0	19 (2 : 17)	.11
I	1	0	0	1	6 (3 :3)	.50
J	1	0	1	0	12 (2 : 10)	.17
K	1	0	1	1	9 (5 : 4)	.56
L	1	1	0	0	26 (2 : 24)	.08
M	1	1	0	1	9 (4 : 5)	.44
N	1	1	1	0	19 (2 : 17)	.11

Note. Each feature could be (1) present or (0) absent. As an example, stimulus A = 0001 means that only a bowtie was added to this Mr. Potato Head character, whereas stimulus $N = 1110$ indicates the presence of a moustache, a hat, and glasses, but no bowtie. For each of the 14 stimuli, there was a specific outcome-probability (P). For example, stimuli A and G appear 19 times each on the 200 trials, 17 times associated with vanilla, and two times associated with chocolate, with a vanilla-outcome probability of .89 (17 times vanilla/19 apparitions = .89). Note that stimuli F and I were equally associated with the 2 categories and were excluded from the analyses.

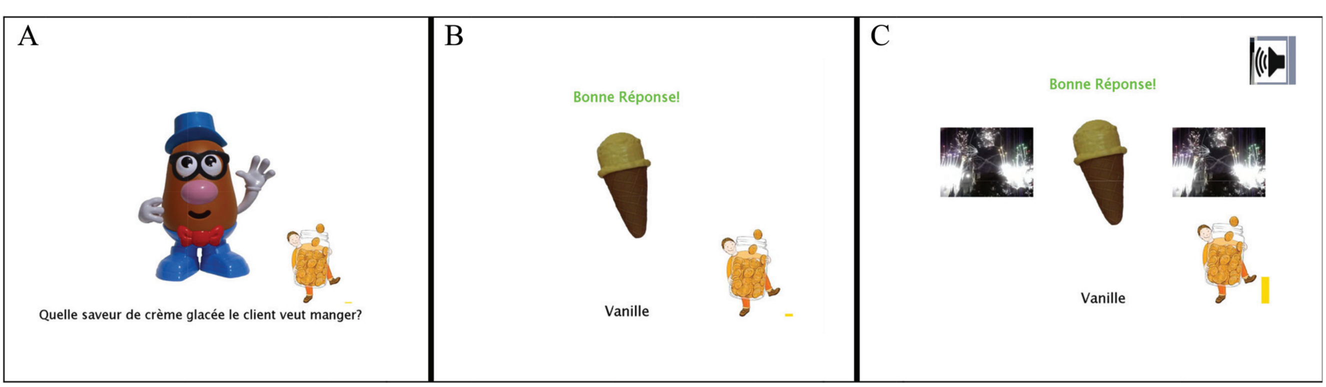
laptop computer. One key on the left side of the keyboard was identified for Vanilla (or apple) and one key on the right side of the keyboard was labeled for Chocolate (or grape). Since atypical language abilities are common in autism, the tasks were designed to require minimal verbal communication. Instructions were presented orally, in addition to simple written instructions and illustrated information on the screen.

Learning Phase

For clarity, the description of each task will use the Mr. Potato Head character as an example throughout (outcome: vanilla or chocolate ice cream); all aspects were equivalent for Ms. Pumpkin (outcome: apple or grape juice).

In the feedback condition (see Feedback Condition section below), the effect of feedback intensity on learning was assessed by comparing learning situations with basic informative feedback (low intensity) versus basic informative feedback with additional but superfluous nonsocial information (high intensity). In the information presentation condition (see Information Presentation Condition section below), learning situations varied in the manner in which information was presented to participants, comparing the effect of isolated (one item at a time, in sequence) versus simultaneous (20 at a time, in arrays) presentation of stimuli on task performance. Each task was composed of three phases for all four situations; (a) a learning phase which differed across the four learning situations; (b) a first 70-trial test phase (Test 1), and (c) a

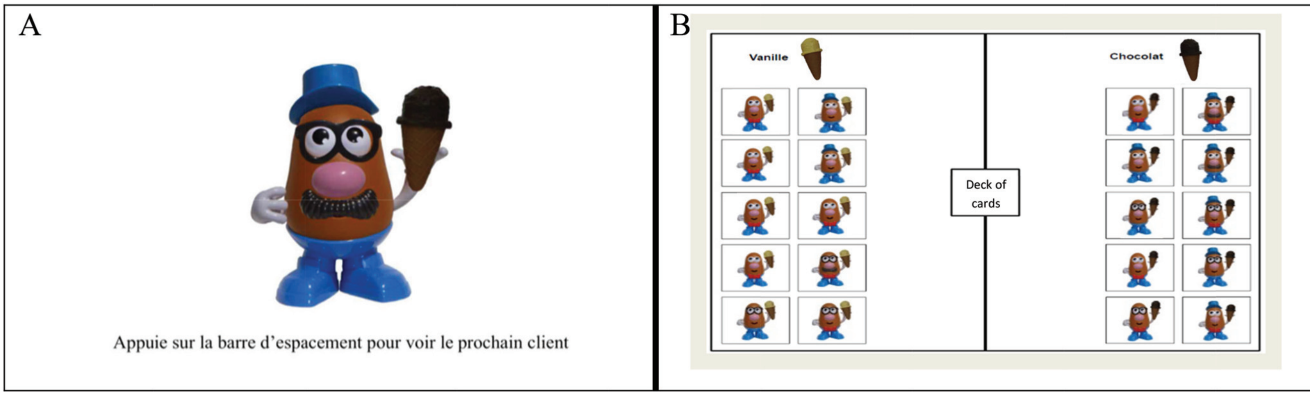
Figure 1
Feedback Condition Stimuli



Note. (A) Both low and high feedback situations: children see one character at a time and have to guess which flavor (vanilla or chocolate) is associated with each character. (B) Low feedback: correct answer in green (light gray) text with coin added to tip jar, incorrect answer (not shown) in red text. (C) High feedback: same as B, but with added animated fireworks (visual and auditory) for correct answers. See the online article for the color version of this figure.

This document is copyrighted by the American Psychological Association or one of its allied publishers.
Content may be shared at no cost, but any requests to reuse this content in part or whole must go through the American Psychological Association.

Figure 2
Information Condition Stimuli



Note. (A) Isolated situation: children see all 200 characters with their associated flavors (vanilla or chocolate) one at a time at their own pace, pressing the space bar when ready to see the next character. (B) Simultaneous situation: children arrange and see arrays of 20 character–flavor associations (10 vanilla, 10 chocolate) at their own pace, until they have seen all 200 stimuli. See the online article for the color version of this figure.

second 70-trial test phase (Test 2). These phases are detailed below.

Feedback Condition. Children were asked to classify the stimuli into two categories by predicting whether the characters, or customers, preferred vanilla or chocolate ice cream. The general instruction consisted of the following sentences: "Each time a customer comes, try to guess whether he prefers vanilla or chocolate ice cream. If you guess correctly, you will earn an extra tip!" Participants were informed that during the first part of the game, they would receive feedback to help them learn the preference of their customers. They were told that they would have to guess at the beginning of the game, but that they might find it easier to guess as the game goes on. For each of the learning trials, a Mr. Potato Head character (without ice cream cone) was shown along with the prompt; "Which flavor do you think he wants?" Children responded by pressing either the vanilla or the chocolate button on the keyboard. There were 200 learning trials for each situation (low vs. high feedback). Each child thus completed 200 learning trials in the low feedback situation with one set of characters in one session, and 200 learning trials in the high feedback situation with the other set of characters in another session. The order of feedback situations (low vs. high feedback) and character sets (Mr. Potato Head vs. Ms. Pumpkin) was counterbalanced across children (Figure 1A).

Low Feedback Situation. In the low feedback situation, feedback was restricted to basic, unimodal informative content defined by (a) the label for the correct answer—that is, vanilla or chocolate, (b) written information in the form of "Good answer" in green or "Wrong answer" in red, and (c) a picture of the expected answer—a vanilla or chocolate ice cream cone. In addition, when the child answered correctly, the bar representing the tip jar on the right side of the screen increased a step. If the child answered incorrectly, there was no removal of previously gained tips. Therefore, all components in the low feedback situation were to some degree informative about either the categories or the performance of the child. See Figure 1B for an example.

High Feedback Situation. In the high feedback situation, the same basic informative feedback was also provided for correct and incorrect answers (picture and written information about the correct/incorrect answer, tip jar representative of performance), but with additional, multimodal and symbolic feedback for correct answers. This consisted of a celebratory visual pattern and sound in the form of animated grayscale visual fireworks, coupled with background (i.e., not loud or startling) sounds of fireworks. Note that the sound volume was adjusted to each child's preferences. See Figure 1C for an example.

For both feedback situations, feedback remained on the screen during 3 seconds; 5 seconds maximum per item was allowed and a 500 ms interstimulus interval was used. If the child did not respond within the 5 seconds limit, it was counted as a missing value and the next trial began. Prior to the learning phase, participants completed five practice trials during which instructions were explained. The 200 trials were presented randomly for each child in each situation.

Information Presentation Condition. To assess the role played by information presentation, half the participants learned first by being presented one stimulus at a time (isolated situation) with the other half presented several stimuli at once (simultaneous situation). Participants were instructed that they would see many different pictures of customers, along with their favorite flavor of ice cream cone (either vanilla or chocolate). Children were instructed to observe the different patterns and to try to learn the customers' preferences: "Look at each customer and try to learn what kind of customers prefer vanilla and which kind of customers prefer chocolate. Later on, you will see more customers without their cones, and be asked to guess which flavor they prefer."

Isolated Situation. In the isolated situation, participants were presented with 200 stimuli on the computer screen in random order, one character at a time and each character with an outcome, that is, holding a vanilla or chocolate ice cream cone (see Figure 2A). Children pressed the space bar when ready to see the next character, with a maximum of 5 seconds allowed per character. Most children in both groups spent approximately 1 to 2 seconds on average looking at each character. No external or explicit feedback was given through the task; learning was only possible by observing the different stimulus–outcome associations. There was a pause offered after the first 100 characters, but most of the

This document is copyrighted by the American Psychological Association or one of its allied publishers.
Content may be shared at no cost, but any requests to reuse this content in part or whole must go through the American Psychological Association.

This document is copyrighted by the American Psychological Association or one of its allied publishers.
Content may be shared at no cost, but any requests to reuse this content in part or whole must go through the American Psychological Association.

children took no pause or only a few seconds' break to stretch then continued immediately with the second hundred characters.

Simultaneous Situation. As illustrated in Figure 2B, stimuli were presented using a physical board (55 × 65 cm) with arrays of cards (each 7.7 cm × 7.7 cm). The 200 characters were divided in 10 sets of 20 cards such that each set presented 10 customers holding a vanilla cone and 10 customers holding a chocolate cone. After the instructions were given (same as in the isolated situation), a first set of 20 cards was presented in a deck in the center of the board and the child was asked to place each of the 20 items on each side of the board so that the 20 cards could be visible at the same time. Children placed the cards one at a time under the relevant category (in each set: 10 items associated with vanilla on the left side of the board and 10 items associated with chocolate on the right side of the board). Again, no external or explicit feedback was given; instead, category information was inherent to the task itself as characters were presented with their outcomes. This situation also allowed children to see different exemplars at the same time, and to compare different outcome associations. After 60 seconds or when the child indicated they had observed enough, the 20 cards were removed and another set of 20 cards was presented, until the child had observed all 200 stimuli. No child in either group took the full 60 seconds allowed. Most of the children observed each set between 15 and 20 seconds.

Test Phase (Test 1 and Test 2)

The learning phase in each of the four situations was followed by two computer-based test phases (the same for each learning situation) in which children classified the same or equivalent 14 stimuli, but this time without any feedback or outcomes. The test phases employed two types of stimuli. Test 1 used the learning-phase stimuli (same 14 characters as seen in learning phase). Children were instructed that they would now see the same customers without their ice cream cone or without feedback and that they would have to predict the correct flavor of ice cream for each customer. Test 2 used equivalent but new stimuli (e.g., a different kind of hat, glasses, bowtie, and/or moustache) requiring generalization of learning. Children were told that they would now see "new" customers and they should try to guess what their preferences are.

Both test phases consisted of each of the 14 stimuli (characters A to N; either same or equivalent) presented five times, for a total of 70 trials. On each of the 70 trials, the children were seeing a character without their ice cream cone and with the prompt; "What flavor do you think he wants?" After children responded by pressing the vanilla or chocolate button on the keyboard, the next trial was presented. No feedback was provided in either test phase; children had to rely on the stimuli–outcome probabilities experienced during the learning phase. A maximum of five seconds per item was allowed, with a 500 ms interstimulus interval. If the child did not respond within 5 seconds, it was counted as a missing value and the next trial began.

Results

Data Analysis

Data were mainly analyzed using IBM SPSS Statistics for Windows, Version 24.0. Statistical comparisons were two-tailed and used an alpha of .05. For some crucial comparisons, additional Bayesian analyses were conducted with JASP package (Version .14.1; JASP Team, 2020) to weigh evidence for null versus alternative hypotheses. Following Lee and Wagenmakers' (2014) classification for interpreting Bayes factors (BF), the level of evidence was deemed inconclusive/anecdotal for BF between .33 and 3, moderate for BF $<$ .33 or $>$ 3, and strong for BF $<$ .1 or $>$ 10.

Both accuracy and response times (RTs) were recorded for the two test phases that followed each of the four learning situations. It is important to note that the children received no instructions with respect to response speed; they were not instructed to respond as quickly as possible (see above for the task instructions). Children's accuracy and RTs across the five nonchance levels of stimulus–outcome probability (.92, .89, .83, .78, .55) were compared to assess the impact of the four different learning situations on categorization performance across the two test phases. Characters F and I, which are equally associated with the two categories (stimulus–outcome probability of 50%), were excluded from the analyses. Accuracy (% correct responses on test phase) was recorded based on the outcome most often associated with a given character. As an example, as character A is more often associated with vanilla, it was the expected answer for this character. For RTs, trials with no response were removed from the analyses (which resulted in less than 5% of missing data).

Learning Analyses

The first comparison was across both conditions. As each child completed two of the four situations, we used mixed linear models in order to compare accuracy across all four learning situations within each group. Second, for each condition (i.e., feedback condition and information condition), total accuracy and RTs were submitted to a 2 (Group) × 2 (Type of Learning Situation: low vs. high; or isolated vs. simultaneous) ANOVA. Then, planned within-group comparisons directly targeting our main objectives were conducted on low versus high feedback learning situations, as well as isolated versus simultaneous learning situations. The results from these planned comparisons were further qualified by repeated measures Bayesian analyses in order to assess the evidence for null over alternative hypothesis (indicated by BF $<$ .33) or for alternative over null hypothesis (indicated by BF $>$ 3).

To verify the effect of stimulus–outcome probability on the performance, another 2 (Group) × 2 (Type of Learning Situation: low vs. high; or isolated vs. simultaneous) × Five Levels of Stimulus–Outcome Probabilities (.55, .78, .83, .89, .92) ANOVA was conducted. We also reported the proportion of children in each group who achieved at least 60% accuracy on Test 1 across the different learning situations.

We then explored associations between Test 1 accuracy (for each learning situation) and IQ (PRI score), and Test 1 accuracy and visual working memory (defined by the Spatial span backward scaled score).

Strategies Analyses

We investigated the strategies used by the children to classify the items of the main test phase (Test Phase 1; 70 same items). To do this, we generated response profiles based on how a child

This document is copyrighted by the American Psychological Association or one of its allied publishers.
Content may be shared at no cost, but any requests to reuse this content in part or whole must go through the American Psychological Association.

would have responded had they followed multicue, one-cue, or singleton strategies (see descriptions below). Then, for each participant, we compared their responses with the expected response profiles, and computed a percentage of agreement between the child's responses and each response profile. The model with the highest percentage of agreement was considered as the one favored by the child. For example, if the responses of a child showed a 70% agreement with a multicue strategy and a 95% agreement with a one-cue strategy, we considered the one-cue strategy to be the main strategy used by the child. We also set a minimum threshold of 70% of agreement with any of the response profiles under which we considered that a child's responses were not consistent enough with any of the strategies tested.

As described in Gluck et al. (2002) and Shohamy et al. (2004), three types of strategies were considered in the current analyses. First, the *multicue strategy* is the optimal strategy and allows children to respond according to the outcome most often associated to each character. Using this strategy, children take into account the combination of all four attributes in order to respond adequately. This strategy allows the child to accurately classify 100% of the 70 items presented. Second, using the *one-cue strategy*, a child bases their decision on the presence or absence of one specific attribute, whatever the presence of the other cues (e.g., the child chooses vanilla whenever the bowtie is present, otherwise chocolate). Moustache and bowtie are two attributes that predict their outcome with high accuracy and could generate correct responses for up to 90% of the 70 items. Glasses and hat are less reliably associated to their outcome and could potentially generate 67% correct responses. The four different one-cue strategies were tested. Third, the *singleton strategy* focuses on the memorization of items that contain a single attribute (e.g., character A containing only the bowtie). A child could learn that bowtie and glasses are associated to vanilla and moustache and hat to chocolate. Thus, when bowtie or glasses or both combined appear, the child would answer vanilla. When moustache or hat or both combined appear, a child would answer chocolate. Therefore, the child is able to classify the six items where only one attribute is present (characters A, B, D, H) or a consistent combination of attributes (characters C and L), but responds randomly when there is an "inconsistent" combination of attributes (e.g., bowtie and hat). Since those six characters appear with high frequency in the test phase, the singleton strategy allows the child to properly classify 77% of the 70 items presented.

Finally, for some of the children, there was no fit with any of the three models (less than 70% agreement with any of the three tested strategies). Either these children did not display a specific and consistent strategy to classify the test items, or they applied another strategy (untested in the current analyses).

Preliminary Analyses

Sex Differences

As the total and feedback condition samples were not sex-matched (greater proportion of girls in the typical group; see Table 1), preliminary analyses were conducted with data from boys only, to verify whether the pattern of results differs from that of boys and girls considered together. A 2 × 5 × 2 mixed ANOVA was run for accuracy, with type of learning situation (either low vs. high; or isolated vs. simultaneous) and stimulus–outcome probability (.92, .89, .83, .78, .55) as within-subject factors and group (autistic vs. typical) as the between-subjects factor. The same analysis was run for RTs. In these two analyses, patterns of results with boys only were the same as with the entire sample (boys and girls together); thus, we present only analyses conducted on the entire sample.

Category Set (Mr. Potato Head Versus Ms. Pumpkin)

As each child completed learning and test phases once with Mr. Potato Head and once with Ms. Pumpkin, preliminary analyses were conducted to verify whether the two sets of stimuli were equivalent with respect to performance. A series of *t* tests were conducted for each group (autistic; typical) and category set separately; no significant differences for either accuracy or RTs (all p values $> .05$) were found when performance for Mr. Potato Head versus Ms. Pumpkin-based characters was compared. The two category sets were thus collapsed for the remaining analyses.

Main Analyses

Comparison Among the Four Learning Situations

For accuracy on Test 1 (same stimuli as learning phase), the mixed model analysis showed a significant discrepancy among the four learning situations for the autistic children, $F_{(3,\ 35.2)}$ 5.491, $p = .003$, $f^2 = .141$. Pairwise comparisons indicated better performance in the simultaneous versus isolated information situation ($p < .001$), as well as trend-level better performance in the simultaneous information versus high feedback situation ($p = .080$). A different profile was found for typical children. The mixed model showed a tendency toward difference in performance among the four situations, $F_{(3,\ 28.3)}$ 2.372, $p = .0902$; $f2 = .051$, driven by better performance on the high versus low feedback situation ($p = .009$) for typical children, with no other significant pairwise differences. See Table 3 and Figure 3.

For accuracy on Test 2 (generalization stimuli), autistic children's performance on the four situations was similar, $F_{(3,\ 34.91)} = 1.079$, $p = .371$. Typical children showed a tendency for discrepancy among the four situations, $F_{(3,\ 31.493)} = 2.597$, $p = .070$; *t*-tests revealed a better performance on the simultaneous versus the isolated information situation ($p = .02$). See Table 3 and Figure 4.

Feedback Condition

Test 1 (Same Stimuli as During Learning Phase). First, the Group (autistic vs. typical) by Feedback Situation (low vs. high) ANOVA revealed no main effect of feedback situation, $F(1, 45)$ 1.672, $p = .203$, $n_p^2 = .036$ on accuracy, and no significant interaction, $F(1, 45)$ 2.234, $p = .142$, n_p^2=.047. There was a trend for a main group effect, $F(1, 45)$ 3.696, $p = .06$, $n_p^2 = .076$, with autistic children having generally lower accuracy compared to typical children. Planned comparisons targeting our main objective revealed that typical children's accuracy was significantly greater, with a moderate effect size, in the high ($M = .68$, $SD = .10$) compared to the low ($M = .60$, SD =.12; $t(24) = 2.409$, $p = .024$, $d = .651$) feedback learning situation. A Bayesian repeated measures ANOVA showed moderate evidence for a difference in performance in the

Table 3

A) Overall Accuracy for Each Learning Situation in Each Test, Means (M) and Standard Deviations (SD); B) Overall RTs (in Seconds) for Each Situation in Each Test, Means (M) and Standard Deviations (SD)

Learning situation	Autistic *M (SD)*	Typical *M (SD)*	*p*
A) Accuracy			
Test 1 (Same stimuli)			
Low feedback	.57 (.15)	.60 (.12)	ns
High feedback	.56 (.17)	.68 (.10)	.005
Isolated	.54 (.12)	.64 (.15)	.02
Simultaneous	.64 (.14)	.66 (.15)	ns
Test 2 (Generalization stimuli)			
Low feedback	.61 (.15)	.61 (.18)	ns
High feedback	.57 (.21)	.67 (.17)	.06
Isolated	.60 (.14)	.58 (.19)	ns
Simultaneous	.64 (.17)	.68 (.15)	ns
B) Reaction time	Autistic *M* (*SD*)	Typical *M* (*SD*)	*p*
Test 1 (Same stimuli)			
Low feedback	1.4780 (.110)	1.1598 (.073)	.02
High feedback	1.5285 (.097)	1.1022 (.063)	.001
Isolated	1.5685 (.104)	1.5828 (.121)	ns
Simultaneous	1.5086 (.097)	1.4516 (.093)	ns
Test 2 (Generalization stimuli)			
Low feedback	1.2997 (.085)	1.1225 (.069)	ns
High feedback	1.3071 (.085)	1.0968 (.049)	.03
Isolated	1.2223 (.066)	1.3780 (.092)	ns
Simultaneous	1.1876 (.065)	1.3040 (.075)	ns

Note. ns = nonsignificant.

This document is copyrighted by the American Psychological Association or one of its allied publishers.
Content may be shared at no cost, but any requests to reuse this content in part or whole must go through the American Psychological Association.

low versus high feedback situations in typical children (*BF* = 4.105), the alternative hypothesis being 4.105 times more likely than the null hypothesis. Autistic children performed with similar (equal) accuracy, with a practically null effect size, in both feedback situations (low $M = .57$, $SD = .15$ versus high $M = .56$, $SD = .17$; $t(21) = .120$, $p = .906$, $d = .031$). A Bayesian analysis revealed moderate evidence in favor of an absence of difference between the situations in autistic children (*BF* = .293), the null hypothesis being 3.42 times more likely than the alternative hypothesis. Typical children were also significantly more accurate than autistic children in the high feedback situation, with a large effect size (t (49) 2.925, $p = .005$, $d = .845$), but accuracy did not differ between groups in the low feedback situation ($t(46)$ .641, $p > .05$, $d = .180$). The proportion of typical children who achieved 60% accuracy or higher on Test 1 was 52% in the low feedback situation and 69% in the high feedback situation, compared to 39% versus 44% in the autistic group, respectively. See Table 3 and Figure 5.

Then, the impact of feedback situation on accuracy according to item probability was assessed with a Group × Feedback Situation × Stimulus–Outcome Probability ANOVA. Percentage of correct responses augmented with increasing stimulus-outcome probability, as shown by a main effect of stimulus–outcome probability ($F(1, 180) = 15.469$, $p < .001$, $n_p^2 = .256$) and a significant linear contrast between percent correct response and stimulus-outcome probability ($F(1, 45) = 37.675$, $p <$ 001, $n_p^2 = .456$). Both autistic and typical groups performed more accurately on higher stimulus-outcome probabilities, with no further interactions (see Figure 6).

For RTs, there was no main effect of feedback situation or probability level. However, there was a main effect of group, $F(1, 44) = 9.548$, $p = .003$, $n_p{}^2 = .178$, with autistic children ($M = 1.47$s, $SD = .57$) taking overall significantly more time to respond than typical children ($M = 1.13$s, $SD = .38$), see Figure 7, Table 3.

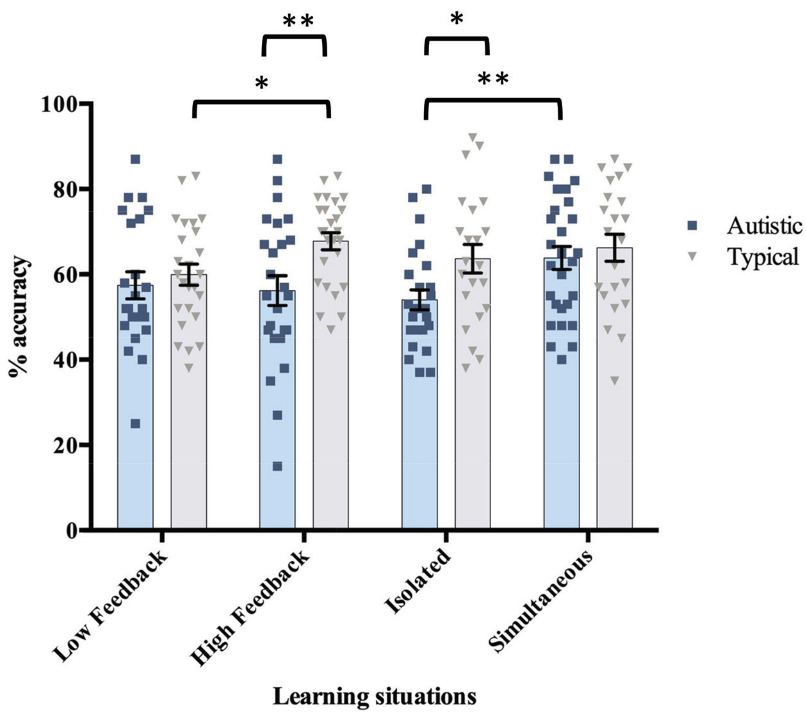
Test 2 (Generalization Stimuli). Autistic and typical children were able to generalize their learning to new stimuli, performing with similar accuracy on Test 2 compared to Test 1 in both low (autistic: $t(20) = .928$, $p = .365$, $d = .197$; typical: $t(22) = .195$, $p = .848$, $d = .033$) and high (autistic: $t(21) = .288$, $p = .776$, $d = .059$; typical: $t(24) = .542$, $p = .593$, $d = .111$) feedback situations. In Test 2, autistic children's performance was similar in the low vs. high feedback situation, as was also the case for typical children (*p*s $>$.05). Comparing groups, there was a trend for better accuracy in typical children than in autistic children in the high feedback situation ($t(45) = 1.9$, $p = .06$), while both groups again showed similar performance in the low feedback situation, $p = .9$ (Table 3, Figure 4).

The Group × Feedback Situation × Stimulus–Outcome Probability ANOVA revealed a main effect of stimulus–outcome probability ($F(1, 156) = 6.155$, $p < .001$, $n^2 = .136$), with percentage of correct responses increasing with higher stimulus–outcome probability. The increase was similar in both groups, with no interaction.

As for RTs, no between-group difference was found in the low feedback situation, while autistic children showed significantly longer RTs compared to typical children in the high feedback situation ($t(45) = 2.209$. $p = .032$, $d =.636$), see Table 3.

Strategy Analysis. In the low feedback situation, 11 of 26 autistic (8 one-cue; 3 multicue) and 12 of 28 typical children (11 one-cue; 1 multicue) showed a performance consistent with one of the three tested types of strategies, that is, multicue, one-cue or singleton strategy. Autistic and typical groups did not differ in proportion of children who used an identified strategy, $\chi^2(1, 54) = .002$, $p = .967$, nor on the type of strategy used,

Figure 3
Test 1 (Same Stimuli) Overall Accuracy Across All Four Learning Situations



Note. Error bars represent standard error of the mean. * $p < .05$. ** $p < .01$. See the online article for the color version of this figure.

This document is copyrighted by the American Psychological Association or one of its allied publishers.
Content may be shared at no cost, but any requests to reuse this content in part or whole must go through the American Psychological Association.

$\chi^2(1, 54) = 1.433$, $p = .231$ (see Figure 8). In the high feedback situation, 15 of 26 autistic (14 one-cue; 1 multicue) and 20 of 28 typical (17 one-cue; 3 multicue) children showed performance consistent with one of the three types of strategies. Autistic and typical groups did not differ on the proportion of children who used an identified strategy, $\chi^2(1, 54) = 1.12$, $p = .29$, nor on the type of strategy used, $\chi^2(1, 54) = 1.59$, $p = .44$ (see Figure 8).

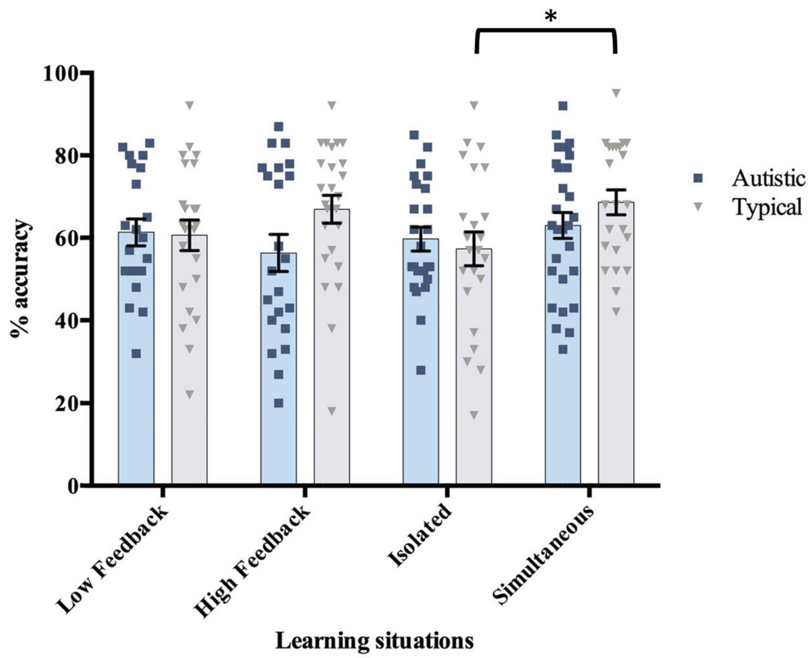
Information Condition

Test 1 (Same Stimuli as During Learning Phase). First, the Group (autistic vs. typical) by Information Situation (isolated vs. simultaneous) ANOVA on total accuracy revealed a main effect of Information Situation, $F(1, 46)$ 10.349, $p = .002$, $n_p^2 = .184$, and a significant interaction between Information Situation and Group, $F(1, 46)$ 4.151, $p = .047$, $n_p^2 = .083$, without a main effect of Group. Planned comparisons revealed that autistic children performed significantly better, and this with a large effect size, in the simultaneous ($M = .64$, $SD = .14$) compared to the isolated ($M = .54$, $SD = .12$; $t(24)$ 4.202, $p < .001$, $d = .830$) situation. A Bayesian repeated measures ANOVA showed very strong evidence for a difference in performance in isolated versus simultaneous situations in autistic children ($BF = 100.576$). Typical children showed similar performance in both situations (isolated $M = .64$, $SD = .15$; simultaneous $M = .66$, $SD =. 15$; $t(21)$ .703, $p = .490$, $d = .168$). Here the Bayesian analysis revealed low to moderate evidence in favor of an absence of difference between the two situations ($BF = .357$), the null hypothesis being 2.8 times more likely than the alternative hypothesis. Autistic children were less accurate than typical children in the isolated situation ($t(45)$ 2.367, $p = .022$, $d = .686$) but performed with similar accuracy in the simultaneous situation ($t(48)$ .566, $p = .574$, $d = .161$). The proportion of children who achieved 60% accuracy or higher on Test 1 was 57% in the isolated situation versus 61% in the simultaneous situation in the typical group, and 27% versus 62% in the autistic group, respectively. Interestingly, 72% of autistic children showed an advantage in the simultaneous versus the isolated situation, compared to 45% of typical children (Table 3, Figure 9).

Then, the Group × Information Situation × Stimulus–Outcome Probability ANOVA further revealed a main effect of stimulus-outcome probability ($F(4, 180)$ 17.497, $p < .001$, $n_p{}^2 = .280$) and a significant three way interaction ($F(1, 45)$ 3.009, $p = .020$, $n_p{}^2 = .063$; see Figure 10). To further characterize the interaction, we collapsed the five levels of stimulus-outcome probability into higher (.92, .89, .83) versus lower (.78, .55) probability levels. At the higher probability level, autistic children performed less accurately than typical children in the isolated information situation (autistic, $M = .54$, $SD = .15$; typical, $M = .69$ (.19), $t(45)$ 3.058 $p = .004$, $d = .888$), but performed similarly to typical children in the simultaneous information situation (autistic, $M = .66$, $SD = .16$; typical, $M = .64$ $SD = .16$, $t(48)$ .378 $p = .707$; see Figure 11).

For RTs, there was no main effect of information situation, stimulus-outcome probability, or group, meaning that autistic (isolated $M = 1.57$s, $SD = .52$; simultaneous $M = 1.50$s, $SD = .52$) and typical (isolated $M = 1.59$s, $SD = .56$; simultaneous $M =$

Figure 4
Test 2 (Generalization Stimuli) Overall Accuracy Across All Four Learning Situations

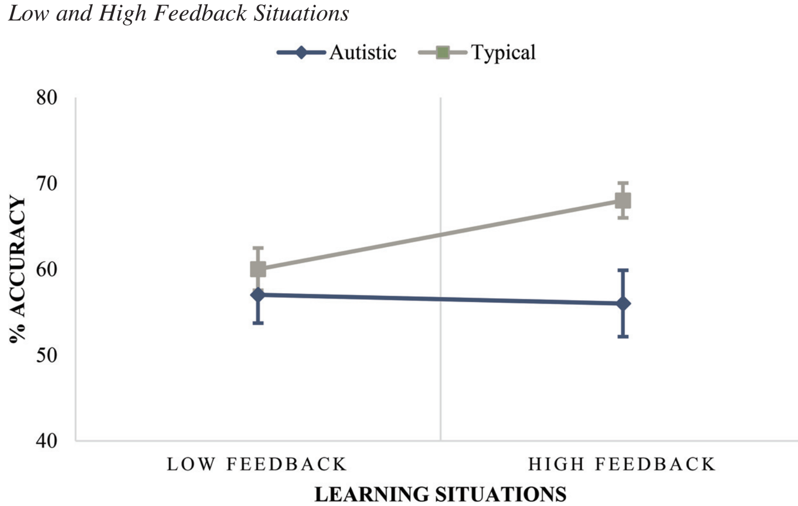


Note. Error bars represent standard error of the mean. * $p < .05$. See the online article for the color version of this figure.

1.45s, *SD* = .44) children had similar RTs, regardless of how information was presented (Table 3) or the probabilistic strength of the stimuli, all *p*s > .05 (Figure 12, Table 3).

Test 2 (Generalization Stimuli). As in the feedback condition, autistic children were able to generalize their learning to new stimuli. This transfer was found for both information presentation situations, with either improved (isolated situation, $t(23)$ 2.650, $p = .014$, $d = .439$) or unchanged (simultaneous situation, $t(27)$ .111, $p = .913$, $d = .015$) accuracy on Test 2 compared to Test 1. Typical children were also able to generalize their learning and

Figure 5
Test 1 (Same Stimuli) Overall Accuracy for Autistic and Typical Children for Low and High Feedback Situations

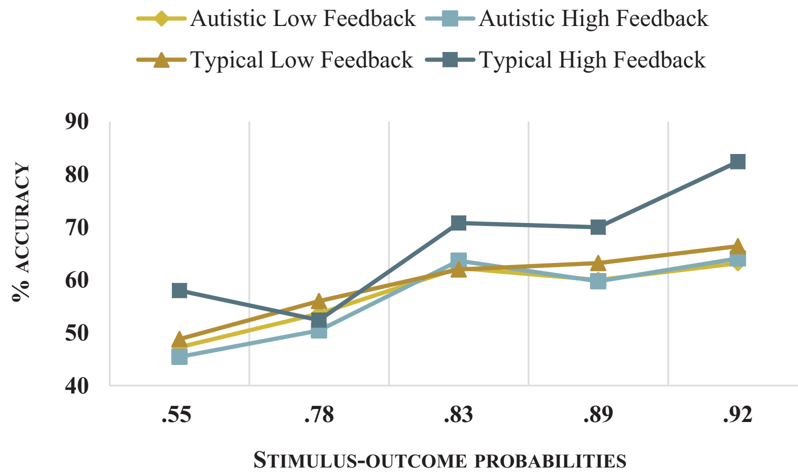


Note. Error bars represent standard error of the mean. See the online article for the color version of this figure.

This document is copyrighted by the American Psychological Association or one of its allied publishers.
Content may be shared at no cost, but any requests to reuse this content in part or whole must go through the American Psychological Association.

Figure 6

Test 1 (Same Stimuli) Mean Accuracy on Each Stimulus–Outcome Probability for Low and High Feedback Situations



Note. See the online article for the color version of this figure.

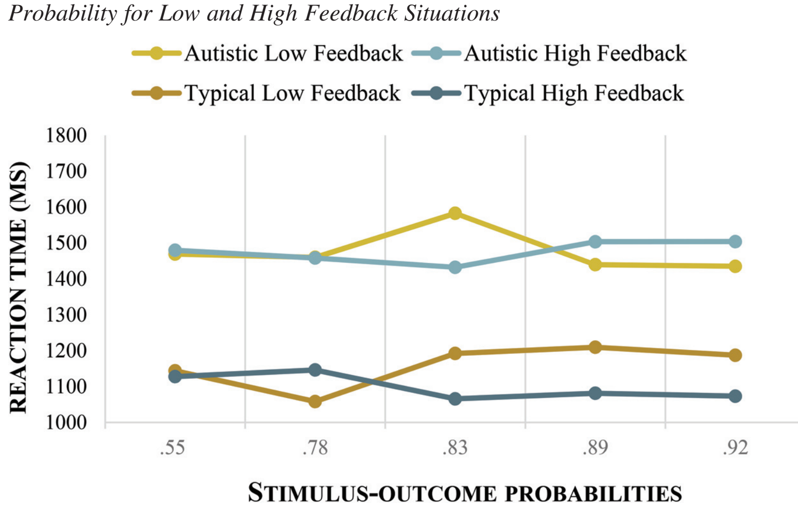
this for both situations (isolated situation, $t(20)$ 1.460, p = .159, d = .310; simultaneous situation, $t(21)$ .789, p = .439, d = .113). Autistic children's Test 1 advantage in the simultaneous versus isolated situation was thus maintained only at a trend level in Test 2 (simultaneous M = .64, SD = .17; isolated M = .60, SD = .14; $t(23)$ 1.810, p = .083, d = .364) whereas Test 2 accuracy tended to be lower in the isolated (M = .57, SD = .19) versus the simultaneous (M = .69, SD = .15; $t(21)$ 2.071, p = .051, d = .017) situation for typical children. Comparing groups, performance was similar on both isolated ($t(45)$ .515, p = .609) and simultaneous ($t(49)$ 1.079, p = .286) situations; see Table 3, and Figure 4.

The Group × Information Situation × Stimulus–Outcome Probability ANOVA on accuracy revealed a main effect of Information Situation, ($F(1, 45)$ = 9.117, p = .004, n_p^2 = .168), where both groups performed better in the simultaneous compared to isolated situation, with no main effect of group or interaction on Test 2 accuracy (both $ps > .05$). There was also a main effect of stimulus–outcome probability ($F(1, 180)$ = 6.152, $p < .001$, n^2 = .120) with percentage of correct responses increasing with higher stimulus–outcome probability. Therefore, as expected, both groups performed more accurately with higher stimulus–outcome probabilities, and changes across level of probability were similar for both groups.

The same three-way mixed ANOVA on RTs revealed no main effect of information situation, stimulus-outcome probability, or group, meaning that autistic (isolated M = 1.22s, SD = .32; simultaneous M = 1.20s, SD = .34) and typical (isolated M = 1.37s, SD = .44; simultaneous M = 1.32s, SD = .38) children had similar

Figure 7

Test 1 (Same Stimuli) Mean Reaction Time (ms) on Each Stimulus–Outcome Probability for Low and High Feedback Situations

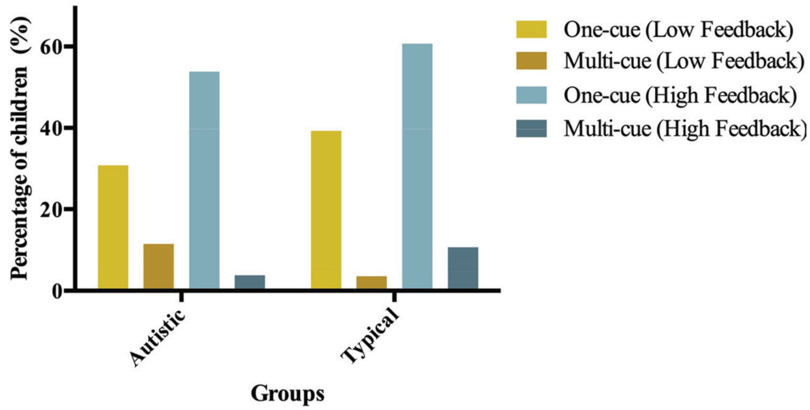


Note. See the online article for the color version of this figure.

This document is copyrighted by the American Psychological Association or one of its allied publishers.
Content may be shared at no cost, but any requests to reuse this content in part or whole must go through the American Psychological Association.

Figure 8

Percentage of Autistic and Typical Children in the Low and High Feedback Situation With Best Fit by the Multicue, the One-Cue or the Singleton Strategy



Note. The model with the highest percentage of agreement (above 70% of agreement) was considered as the one favored by the child. See the online article for the color version of this figure.

RTs, regardless of how information was presented (Table 3) or the probability of the stimuli, all *p*s $>.05$.

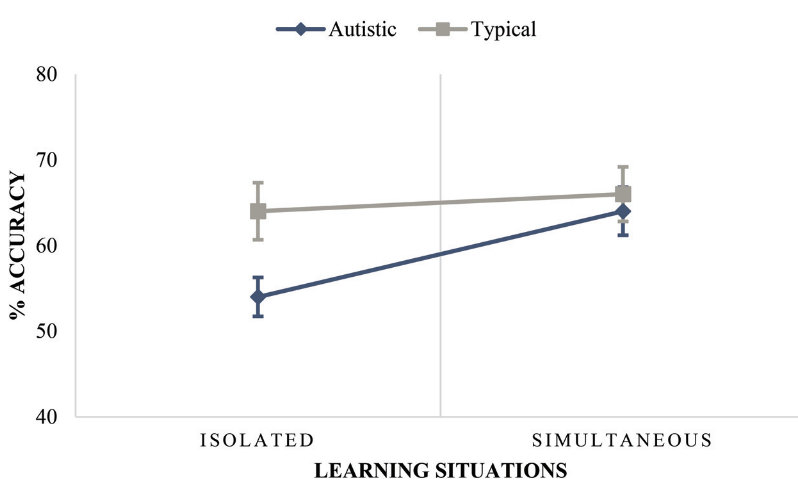
Strategy Analysis. In the isolated situation, nine of 28 autistic (9 one-cue) and 14 of 24 typical (10 one-cue; 4 multicue) children showed performance consistent with one of the three types of strategies. Interestingly, the difference between autistic and typical groups both on the proportion of children who used one or the other strategy, $\chi^2(1, 52) = 3.594$, $p = .058$, and on the type of strategy used, $\chi^2(1, 52) = 3.11$, $p = .078$, is marginally significant (see Figure 13). In the simultaneous situation, 15 of 28 autistic (10 one-cue; 5 multicue) and 14 of 24 typical (12 one-cue; 1 singleton; 1 multicue) children showed performance consistent with one of the three models, that is, multicue, one-cue, or singleton strategy. Autistic and typical groups did not differ on the proportion of children who used an identified strategy, $\chi^2(1, 52) = .12$, $p = .730$, nor on the type of strategy used, $\chi^2(2, 52) = 3.82$, $p = .148$, (see Figure 13).

Exploratory Correlational Analyses

Additional analyses demonstrated that IQ (PRI score) was not significantly associated with Test 1 accuracy in any of the four situations, for both autistic and typical groups (all *r*s: $p > .05$), concordant with the literature suggesting that implicit learning is relatively independent of IQ (Gebauer & Mackintosh, 2007; Reber et al., 1991). In addition, there was no association between visual working memory (spatial span backward) and accuracy (all *r*s: $p > .05$), except for autistic children in the isolated situation

Figure 9

Test 1 (Same Stimuli) Overall Accuracy for Autistic and Typical Children for Isolated and Simultaneous Situations

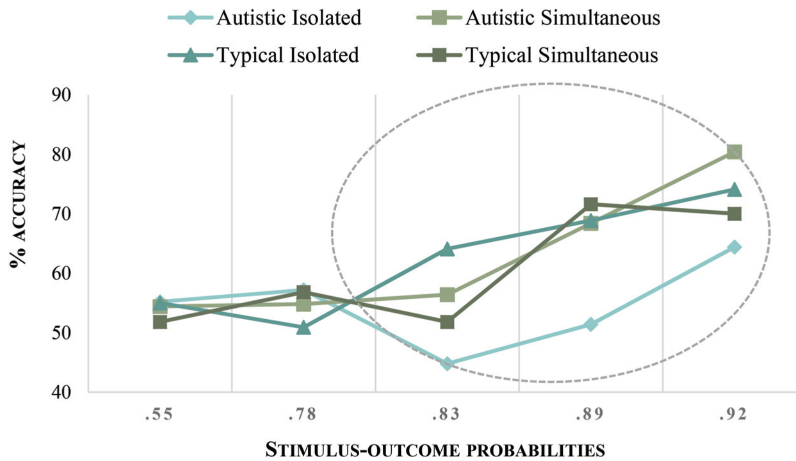


Note. Error bars represent standard error of the mean. See the online article for the color version of this figure.

This document is copyrighted by the American Psychological Association or one of its allied publishers.
Content may be shared at no cost, but any requests to reuse this content in part or whole must go through the American Psychological Association.

Figure 10

Test 1 (Same Stimuli) Mean Accuracy on Each Stimulus–Outcome Probability for Isolated and Simultaneous Situations



Note. See the online article for the color version of this figure.

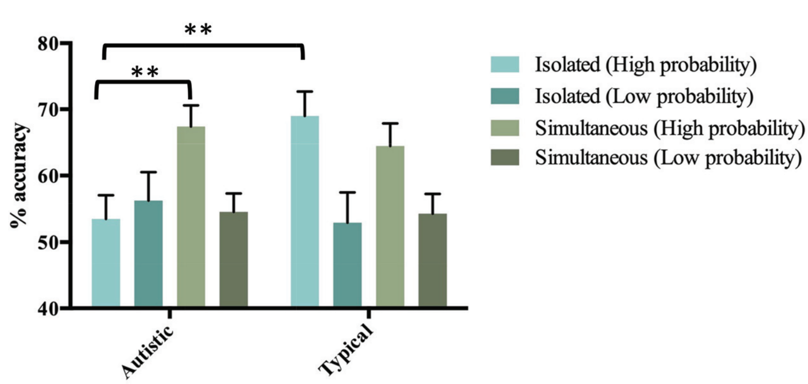
(r = .456, p = .025), suggesting greater reliance on executive functions for autistics in that situation.

Discussion

The goal of this study was to compare performance on a probabilistic classification task in autistic versus typical children across situations which varied in the way feedback and information were provided during learning. Both autistic and typical children were able to learn novel categories across all four different learning situations assessed, adding to the growing literature showing that autistics can and do learn implicitly from complex probabilistic information, given the opportunity (Foti et al., 2015; Obeid et al., 2016; Zwart et al., 2019; Zwart, Vissers, & Maes, 2018; Zwart, Vissers, Kessels, et al., 2018). Across all four learning situations, typical children were better able to categorize after learning with high-intensity external feedback, whereas autistic children were most accurate after learning with simultaneously presented information. Across the two situations in each condition, only typical children performed better with high (vs. low) intensity feedback, but only autistic children performed better with simultaneous (vs. isolated) information. Between-group comparisons demonstrated that with either high intensity feedback or when information was presented in isolation, autistic children performed less accurately than typical children. In contrast, with both low intensity feedback and simultaneously presented information, group performance did not differ in accuracy. Groups were similar in how their accuracy was affected by the full range of stimulus-outcome probabilities, but at the highest probability levels, autistic children were advantaged by simultaneously-presented information.

Figure 11

Test 1 (Same Stimuli) Mean Accuracy for Combined High (.92, .89, .83) Versus Low (.78, .55) Stimulus–Outcome Probability for Isolated and Simultaneous Situations

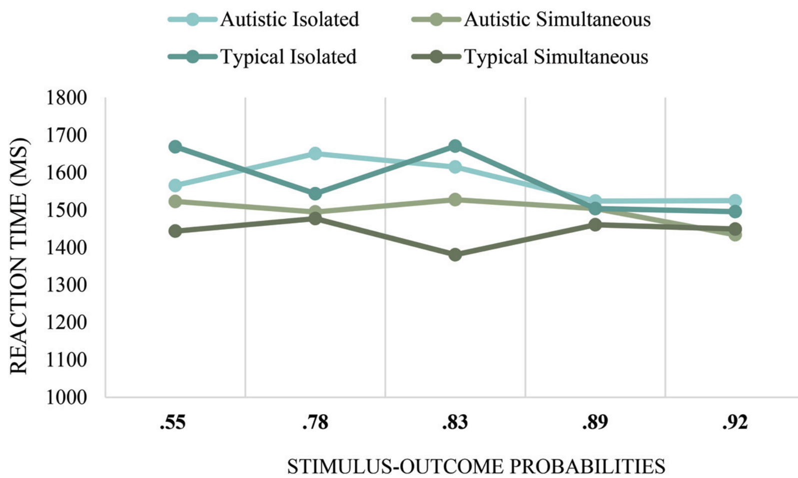


Note. ** $p < .01$. See the online article for the color version of this figure.

This document is copyrighted by the American Psychological Association or one of its allied publishers.
Content may be shared at no cost, but any requests to reuse this content in part or whole must go through the American Psychological Association.

Figure 12

Test 1 (Same Stimuli) Mean Reaction Time on Each Stimulus–Outcome Probability for Isolated and Simultaneous Situations



Note. See the online article for the color version of this figure .

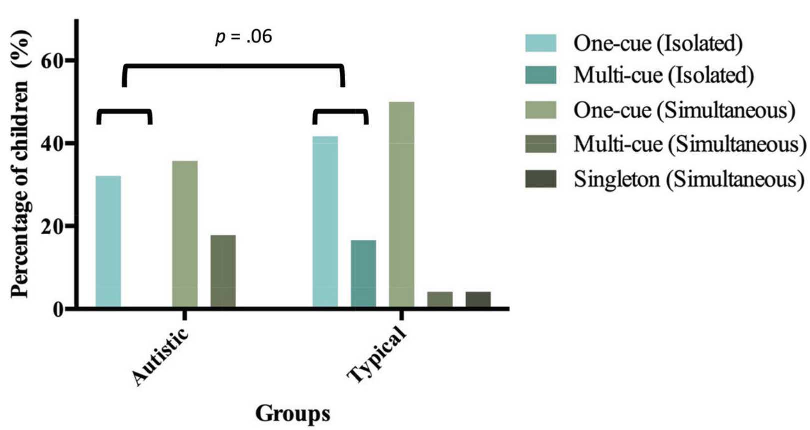
Both autistic and typical groups were able to generalize their learning to new stimuli, with little difference in accuracy either within groups across learning situations, or between groups for the same situation. These results do not support the influential view that autistics are impaired in generalizing what they learn (Davis & Plaisted-Grant, 2015). Regarding response times, although no instructions were provided to participants to perform rapidly, autistic children were slower to respond than typical children in both feedback learning situations (low- and high-intensity), and this slower response carried over into the generalization phase for the high intensity feedback situation. Importantly, no between-group differences in response time was found in the two information presentation situations, neither of which used external feedback.

Type and Intensity of Feedback: A Different Role in Autism?

Overall, we found no evidence that school-aged autistic children are unmotivated to learn or require frequent, elaborate, and/or potent external feedback (reward or reinforcers) to do so. When external feedback was provided, the group that benefited from learning with more elaborate—that is, high-intensity—trial-by-trial feedback was the typical children, not the autistic children. These results do not tell us how much feedback and which feedback elements were used by each child (written text and/or picture of cone and/or visual and auditory animated fireworks). However, they do suggest that augmenting strictly informative feedback with elaborate elements adding no supplementary information—

Figure 13

Percentage of Autistic and Typical Children in the Isolated and Simultaneous Situations With Best Fit by the Multicue, the One-Cue or the Singleton Strategy



Note. The model with the highest percentage of agreement (above 70% of agreement) was considered as the one favored by the child. See the online article for the color version of this figure.

This document is copyrighted by the American Psychological Association or one of its allied publishers.
Content may be shared at no cost, but any requests to reuse this content in part or whole must go through the American Psychological Association.

This document is copyrighted by the American Psychological Association or one of its allied publishers.
Content may be shared at no cost, but any requests to reuse this content in part or whole must go through the American Psychological Association.

elements that in practice are usually intended to be rewarding and motivating—did not help autistic children learn. Groups might not find all types of feedback equally engaging and/or useful for learning. What might help typical children's learning may not work for autistics; therefore, amplifying strategies that are usually supportive for a typical child are not necessarily effective in autism.

In addition, both groups were able to learn and generalize their learning without any external feedback at all, as shown in the feedback-free information condition where children were required to learn complex regularities from observation alone. This finding aligns with the observation in the savant and hyperlexia literatures (e.g., Atkin & Lorch, 2006; Happé & Frith, 2009) that learning itself can be motivating for autistic children, sometimes extraordinarily so, at least in some situations, in which the availability of information and how it is presented may play an important role.

Access to and Manipulation of Information

The information condition results, taken alongside the feedback condition results, converge to suggest that the best situation for learning in autism, among the four offered, is one in which autistics have free access to simultaneously presented arrays of complex information. The simultaneous information situation, by its structure, offers more information to be processed at the same time compared to the isolated information situation, but also compared to both the high and low feedback situations. Both the opportunity to handle and arrange information, and the greater quantity of relevant information available at the same time, may have contributed to autistic children's performance. Unlike any of the other learning situations, the simultaneous situation allowed autistic children to manipulate and arrange the information as they wished, and to combine information across levels and scales, from single features and characters to patterns across and between entire arrays (Mottron et al., 2009). It seems that autistic children are more easily capable of extracting the complex regularities of novel categories when more multilevel information is provided at the same time, and/or they can manipulate, interact with and arrange this larger amount of information while learning.

In short, learning by autistic children in our task was not necessarily facilitated by providing a greater amount of external feedback (adding extraneous elements to the task) but rather by providing a greater amount of task-relevant information at the same time. An advantage in perceptual capacity in autism, as has been found in a growing literature (Remington et al., 2012; Remington & Fairnie, 2017; Remington et al., 2019; Tillmann et al., 2021), would give autistics an ability to process more information at once, suggesting that the free availability of more information to learn from, versus the use of extraneous feedback, would benefit autistics. This is consistent with the direction of our findings, which also showed that learning strategies were similar across groups, leaving group differences in performance across learning situations that were not accompanied by group differences in the strategies examined here. The strategies we assessed were limited, however, to those based on the probability of three response profiles or models, and which may not capture other aspects of learning. In addition, there is the more general issue of implicit versus explicit learning strategy use in autism. Here it has been suggested that learning task designs that disrupt implicit strategies and/or encourage explicit strategies, such as the simplification, slowing, and/or interruption of information presentation (e.g., long response–stimulus intervals, simplified sequences, superfluous animations) will hinder learning in autism (Brown et al., 2010; Gaigg et al., 2020). Interestingly, the sole association we found between task performance and working memory was for autistic children in the isolated situation, the same situation in which the fewest autistic children used one of the three identified strategies and "easiest" (high probability) items remained difficult to classify. All these findings again suggest that breaking down information into small, sequentially presented pieces makes learning more effortful for autistic children.

Conclusion

Our findings are nuanced but suggest clear emerging directions despite the narrow confines of our task, its short timespan, limited and specific stimuli, and relatively minor manipulations. For example, the simultaneous situation falls well short in quantity and complexity when compared to the arrays of information autistic children may use when spontaneously learning in exceptional ways (e.g., Kissine et al., 2019; Ostrolenk et al., 2017). Conversely, the isolated stimuli were not as simplified, nor the intense feedback as elaborate, as in some autism interventions. Situations featuring simplified information and/or frequent or extraneous feedback (Broadbent & Stokes, 2013; Crawley et al., 2019; Pellecchia et al., 2020) may lead to the undermining and thus underestimation of autistic learning. For example, in Scott-Van Zeeland, Dapretto, et al. (2010), a simplified probabilistic task was combined with elaborate social and nonsocial feedback, resulting in at-chance autistic performance; while in Gaigg et al. (2020), autistic adults and children showed "a marked absence" of learning when presented with a highly simplified but elaborately animated repetitive sequence. Autistic learning may also be underestimated if any evidence of learning is wrongly interpreted as evidence for an effective and/or optimal intervention. In our study, autistic children could indeed learn in all situations. Yet, comparisons of performance found some situations hampered their learning when compared to typical children's and/or when compared to better situations for autistic learning. These kinds of comparisons are not features of the autism intervention literature, nor are assessments which would capture the plausibly greater effort required of the autistic children in our study, reflected in their slower performance than typical children, after learning with (vs. without) external feedback.

There are conflicting views of learning in autism which lead to different portrayals of and predictions about the same population. On the one hand, learning in autism would be impeded by numerous proposed autistic deficits (poor motivation, stimulus overselectivity, executive dysfunction, failure to generalize, sensory dysfunction, etc.). In this view, autistics may learn but only via highly effortful, gradual, explicit, simplified, and intensified forms of instruction (e.g., Cannon et al., 2011; Hume et al., 2021; Kenworthy et al., 2014; Leaf & McEachin, 1999; Lovaas & Smith, 1988; Lovaas, 2003; Mandell et al., 2013; Odom et al., 2010; Smith, 2001; Wong et al., 2015). On the other hand, learning in autism would be atypical and potentially exceptional, or outstanding, in some situations. Given the opportunity, autistics may spontaneously extract regularities from large arrays of complex information (Dawson et al., 2008; Mottron et al., 2009, 2013).

These disparate views generate contrasting predictions about situations that may benefit or hinder autistic learning. We found that autistic children were hindered by situations representing common practices under the dominant view: that is, the use of high-intensity feedback, and the use of simplified information presented in small increments one at a time. At the same time, and as predicted by an emerging view, we found that autistic children benefited from a feedback-free situation where they have access to large quantities of simultaneously presented complex information.

Context of Research

This research was conducted as part of the first author's PhD research project, which involves a series of experiments investigating learning processes in autism. Our research group has worked toward better understanding of learning and intelligence in autism, and of the uneven cognitive profiles characteristic of autistic individuals. This work includes proposals that perception may take a larger, more autonomous role in autistic cognition (Mottron et al., 2006), allowing autistics to productively engage perception in an atypically wide range of cognitive tasks (Samson et al., 2012; Soulières et al., 2009). We have also demonstrated that estimates of intelligence in autism may vary dramatically across different tests (Wechsler scales vs. Raven's Progressive Matrices; e.g., Courchesne et al., 2015; Dawson et al., 2007). This result has been replicated (e.g., Charman et al., 2011; reviewed in Morsanyi et al., 2020) and suggests an important role for how information is presented in autistic performance. Here we studied two basic components of learning situations, feedback and information presentation. Our findings suggest that learning in autism is supported by greater simultaneous access to information requiring no external feedback, which is consistent with our proposal of an atypical autistic capacity in processing arrays of information across levels and scales (Mottron et al., 2009). Moving forward, we plan to use eye-tracking technology during categorization in autistic and typical children, to compare similarities and differences in their visual attention patterns after they have learned in different situations.

References

American Psychiatric Association. (2000). *Diagnostic and statistical manual of mental disorders: DSM–IV–TR* (4th ed.).

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders (DSM-5®)*. https://doi.org/10.1176/appi.books.9780890425596

Atkin, K., & Lorch, M. P. (2006). Hyperlexia in a 4-year-old boy with autistic spectrum disorder. *Journal of Neurolinguistics*, *19*(4), 253–269. https://doi.org/10.1016/j.jneuroling.2005.11.006

Baumeister, S., Moessnang, C., Bast, N., Hohmann, S., Tillman, J., Goyard, D., Charman, T., Ambrosino, S., Baron-Cohen, S., Beckmann, C., Bölte, S., Bourgeron, T., Rausch, A., Crawley, D, Dell'Acqua, F., Dumas, G., Durston, S., Ecker, C., Floris, D. L., Frouin, V., . . . the AIMS-2-TRIALS group. (2020). Attenuated anticipation of social and monetary rewards in autism spectrum disorders. *bioRxiv*. Advance online publication. https://doi.org/10.1101/2020.07.06.186650

Broadbent, J., & Stokes, M. A. (2013). Removal of negative feedback enhances WCST performance for individuals with ASD. *Research in Autism Spectrum Disorders*, *7*(6), 785–792. https://doi.org/10.1016/j.rasd.2013.03.002

Brown, J., Aczel, B., Jiménez, L., Kaufman, S. B., & Grant, K. P. (2010). Intact implicit learning in autism spectrum conditions. *Quarterly Journal of Experimental Psychology*, *63*(9), 1789–1812. https://doi.org/10.1080/17470210903536910

Cannon, L., Kenworthy, L., Alexander, C., Werner, M. A., & Anthony, L. G. (2011). *Unstuck and on target: An executive function curriculum to improve flexibility for children with autism spectrum disorders*. Brookes.

Cannon, J., O'Brien, A. M., Bungert, L., & Sinha, P. (2021). Prediction in autism spectrum disorder: A systematic review of empirical evidence. *Autism Research*, *14*(4), 604–630. https://doi.org/10.1002/aur.2482

Charman, T., Pickles, A., Simonoff, E., Chandler, S., Loucas, T., & Baird, G. (2011). IQ in children with autism spectrum disorders: Data from the Special Needs and Autism Project (SNAP). *Psychological Medicine*, *41*(3), 619–627. https://doi.org/10.1017/S0033291710000991

Church, B. A., Krauss, M. S., Lopata, C., Toomey, J. A., Thomeer, M. L., Coutinho, M. V., Volker, M. A., & Mercado, E., III (2010). Atypical categorization in children with high-functioning autism spectrum disorder. *Psychonomic Bulletin & Review*, *17*(6), 862–868. https://doi.org/10.3758/PBR.17.6.862

Clements, C. C., Zoltowski, A. R., Yankowitz, L. D., Yerys, B. E., Schultz, R. T., & Herrington, J. D. (2018). Evaluation of the social motivation hypothesis of autism: A systematic review and meta-analysis. *JAMA Psychiatry*, *75*(8), 797–808. https://doi.org/10.1001/jamapsychiatry.2018.1100

Cohen, J. (1988). The effect size index: d. In J. Cohen, *Statistical power analysis for the behavioral sciences* (2nd ed., pp. 20–26). Erlbaum.

Cooper, J. O., Heron, T. E., & Heward, W. L. (2007). *Applied behavior analysis* (2nd ed.). Pearson/Prentice Hall.

Cooper, J. O., Heron, T. E., & Heward, W. L. (2020). *Applied behavior analysis*. Pearson Education. https://doi.org/10.26741/abaespana/2020.cooper3e

Courchesne, V., Meilleur, A. A. S., Poulin-Lord, M. P., Dawson, M., & Soulières, I. (2015). Autistic children at risk of being underestimated: School-based pilot study of a strength-informed assessment. *Molecular Autism*, *6*(1), 12. https://doi.org/10.1186/s13229-015-0006-3

Cowen, T. (2011). *An economic and rational choice approach to the autism spectrum and human neurodiversity (GMU Working Paper in Economics (No. 11-58))*. https://ssrn.com/abstract=1975809 or https://doi.org/10.2139/ssrn.1975809

Crawley, D., Zhang, L., Jones, E. J., Ahmad, J., San Jose Caceres, A., Oakley, B., Charman, T., Buitelaar, J., Murphy, D., Chatham, C. H., den Ouden, H., & Loth, E. (2019). *Modeling cognitive flexibility in autism spectrum disorder and typical development reveals comparable developmental shifts in learning mechanisms*. https://doi.org/10.31234/osf.io/h7jcm

Davis, G., & Plaisted-Grant, K. (2015). Low endogenous neural noise in autism. *Autism*, *19*(3), 351–362. https://doi.org/10.1177/1362361314552198

Dawson, M., Mottron, L., & Gernsbacher, M. A. (2008). Learning in autism. In J. H. Byrne & H. Roediger (Eds.), *Learning and memory: A comprehensive reference: Cognitive psychology* (pp. 759–772). Elsevier.

Dawson, M., Soulières, I., Gernsbacher, M. A., & Mottron, L. (2007). The level and nature of autistic intelligence. *Psychological Science*, *18*(8), 657–662. https://doi.org/10.1111/j.1467-9280.2007.01954.x

Eigsti, I. M., & Mayo, J. (2011). Implicit learning in ASD. In D. A. Fein (Ed.), *The neuropsychology of autism* (pp. 267–279). Oxford University Press.

Foti, F., De Crescenzo, F., Vivanti, G., Menghini, D., & Vicari, S. (2015). Implicit learning in individuals with autism spectrum disorders: A meta-analysis. *Psychological Medicine*, *45*(5), 897–910. https://doi.org/10.1017/S0033291714001950

Gaigg, S. B., Krug, M. K., Solomon, M., Roestorf, A., Derwent, C., Anns, S., Bowler, D. M., Rivera, S., Nordahl, C. W., & Jones, E. J. H. (2020). Eye-tracking reveals absent repetition learning across the autism

This document is copyrighted by the American Psychological Association or one of its allied publishers.
Content may be shared at no cost, but any requests to reuse this content in part or whole must go through the American Psychological Association.

This document is copyrighted by the American Psychological Association or one of its allied publishers.
Content may be shared at no cost, but any requests to reuse this content in part or whole must go through the American Psychological Association.

spectrum: Evidence from a passive viewing task. *Autism Research*, *13*(11), 1929–1946. https://doi.org/10.1002/aur.2368

Gebauer, G. F., & Mackintosh, N. J. (2007). Psychometric intelligence dissociates implicit and explicit learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *33*(1), 34–54. https://doi.org/10.1037/0278-7393.33.1.34

Gluck, M. A., Shohamy, D., & Myers, C. (2002). How do people solve the "weather prediction" task? Individual variability in strategies for probabilistic category learning. *Learning & Memory*, *9*(6), 408–418. https://doi.org/10.1101/lm.45202

Haebig, E., Saffran, J. R., & Ellis Weismer, S. (2017). Statistical word learning in children with autism spectrum disorder and specific language impairment. *Journal of Child Psychology and Psychiatry*, *58*(11), 1251–1263. https://doi.org/10.1111/jcpp.12734

Happé, F., & Frith, U. (2009). The beautiful otherness of the autistic mind. *Philosophical Transactions of the Royal Society of London, Series B: Biological Sciences*, *364*, 1345–1350. https://doi.org/10.1098/rstb.2009.0009

Heaton, P., & Wallace, G. L. (2004). Annotation: The savant syndrome. *Journal of Child Psychology and Psychiatry*, *45*(5), 899–911. https://doi.org/10.1111/j.1469-7610.2004.t01-1-00284.x

Hermelin, B., & O'Connor, N. (1967). Remembering of words by psychotic and subnormal children. *British Journal of Psychology*, *58*(3), 213–218. https://doi.org/10.1111/j.2044-8295.1967.tb01075.x

Hume, K., Steinbrenner, J. R., Odom, S. L., Morin, K. L., Nowell, S. W., Tomaszewski, B., Szendrey, S., McIntyre, N. S., Yücesoy-Özkan, S., & Savage, M. N. (2021). Evidence-based practices for children, youth, and young adults with autism: Third generation review. *Journal of Autism and Developmental Disorders*. Advance online publication. https://doi.org/10.1007/s10803-020-04844-2

JASP Team. (2020). JASP (Version 0.14.1) [Computer software]. https://jasp-stats.org

Kenworthy, L., Anthony, L. G., Naiman, D. Q., Cannon, L., Wills, M. C., Luong-Tran, C., Werner, M. A., Alexander, K. C., Strang, J., Bal, E., Sokoloff, J. L, & Wallace, G. L. (2014). Randomized controlled effectiveness trial of executive function intervention for children on the autism spectrum. *Journal of Child Psychology and Psychiatry*, *55*(4), 374–383. https://doi.org/10.1111/jcpp.12161

Kissine, M., & Geelhand, P. (2019). Brief report: Acoustic evidence for increased articulatory stability in the speech of adults with autism spectrum disorder. *Journal of Autism and Developmental Disorders*, *49*(6), 2572–2580. https://doi.org/10.1007/s10803-019-03905-5

Kissine, M., Luffin, X., Aiad, F., Bourourou, R., Deliens, G., & Gaddour, N. (2019). Noncolloquial Arabic in Tunisian children with autism spectrum disorder: A possible instance of language acquisition in a noninteractive context. *Language Learning*, *69*(1), 44–70. https://doi.org/10.1111/lang.12312

Koegel, L. K., Ashbaugh, K., & Koegel, R. L. (2016). Pivotal response treatment. In R. Lang, T. B. Hancock, & N. Singh (Eds.), *Early intervention for young children with autism spectrum disorder* (pp. 85–112). Springer. https://doi.org/10.1007/978-3-319-30925-5_4

Koegel, R. L., Koegel, L. K., & McNerney, E. K. (2001). Pivotal areas in intervention for autism. *Journal of Clinical Child Psychology*, *30*(1), 19–32. https://doi.org/10.1207/S15374424JCCP3001_4

Leaf, R. B., & McEachin, J. (1999). *A work in progress: Behavior management strategies and a curriculum for intensive behavioral treatment of autism*. DRL Books.

Lee, M. D., & Wagenmakers, E. J. (2014). *Bayesian cognitive modeling: A practical course*. Cambridge University Press.

Lord, C., Risi, S., Lambrecht, L., Cook, E. H., Jr. Leventhal, B. L., DiLavore, P. C., Pickles, A., & Rutter, M. (2000). The autism diagnostic observation schedule-generic: A standard measure of social and communication deficits associated with the spectrum of autism. *Journal of Autism and Developmental Disorders*, *30*(3), 205–223. https://doi.org/10.1023/A:1005592401947

Lord, C., Rutter, M., & Le Couteur, A. (1994). Autism Diagnostic Interview-Revised: A revised version of a diagnostic interview for caregivers of individuals with possible pervasive developmental disorders. *Journal of Autism and Developmental Disorders*, *24*(5), 659–685. https://doi.org/10.1007/BF02172145

Lovaas, O. I. (2003). *Teaching individuals with developmental delays: Basic intervention techniques*. Pro-Ed.

Lovaas, O. I., & Smith, T. (1988). Intensive behavioral treatment for young autistic children. In B. B. Lahey & A. E. Kazdin (Eds.), *Advances in clinical child psychology* (pp. 285–324). Springer. https://doi.org/10.1007/978-1-4613-9829-5_8

Mandell, D. S., Stahmer, A. C., Shin, S., Xie, M., Reisinger, E., & Marcus, S. C. (2013). The role of treatment fidelity on outcomes during a randomized field trial of an autism intervention. *Autism*, *17*(3), 281–295. https://doi.org/10.1177/1362361312473666

Maurice, C. E., Green, G. E., & Luce, S. C. (1996). *Behavioral intervention for young children with autism: A manual for parents and professionals*. Pro-Ed.

Mayo, J., & Eigsti, I. M. (2012). Brief report: A comparison of statistical learning in school-aged children with high functioning autism and typically developing peers. *Journal of Autism and Developmental Disorders*, *42*(11), 2476–2485. https://doi.org/10.1007/s10803-012-1493-0

Mercado, E., III Chow, K., Church, B. A., & Lopata, C. (2020). Perceptual category learning in autism spectrum disorder: Truth and consequences. *Neuroscience and Biobehavioral Reviews*, *118*, 689–703. https://doi.org/10.1016/j.neubiorev.2020.08.016

Mercado, E. I. I. I., Church, B. A., Coutinho, M. V. C., Dovgopoly, A., Lopata, C. J., Toomey, J. A., & Thomeer, M. L. (2015). Heterogeneity in perceptual category learning by high functioning children with autism spectrum disorder. *Frontiers in Integrative Neuroscience*, *9*, 42. https://doi.org/10.3389/fnint.2015.00042

Molesworth, C. J., Bowler, D. M., & Hampton, J. A. (2005). The prototype effect in recognition memory: Intact in autism? *Journal of Child Psychology and Psychiatry*, *46*(6), 661–672. https://doi.org/10.1111/j.1469-7610.2004.00383.x

Morsanyi, K., Stamenković, D., & Holyoak, K. J. (2020). Analogical reasoning in autism: A systematic review and meta-analysis. In K. Morsanyi & R. M. J. Byrne (Eds.), *Thinking, reasoning, and decision making in autism* (pp. 59–87). Routledge.

Mottron, L., Bouvet, L., Bonnel, A., Samson, F., Burack, J. A., Dawson, M., & Heaton, P. (2013). Veridical mapping in the development of exceptional autistic abilities. *Neuroscience and Biobehavioral Reviews*, *37*(2), 209–228. https://doi.org/10.1016/j.neubiorev.2012.11.016

Mottron, L., Dawson, M., & Soulieres, I. (2009). Enhanced perception in savant syndrome: patterns, structure and creativity. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*(1522), 1385–1391. https://doi.org/10.1098/rstb.2008.0333

Mottron, L., Dawson, M., Soulières, I., Hubert, B., & Burack, J. (2006). Enhanced perceptual functioning in autism: An update, and eight principles of autistic perception. *Journal of Autism and Developmental Disorders*, *36*(1), 27–43. https://doi.org/10.1007/s10803-005-0040-7

Obeid, R., Brooks, P. J., Powers, K. L., Gillespie-Lynch, K., & Lum, J. A. G. (2016). Statistical learning in specific language impairment and autism spectrum disorder: A meta-analysis. *Frontiers in Psychology*, *7*, 1245. https://doi.org/10.3389/fpsyg.2016.01245

Odom, S. L., Boyd, B. A., Hall, L. J., & Hume, K. (2010). Evaluation of comprehensive treatment models for individuals with autism spectrum disorders. *Journal of Autism and Developmental Disorders*, *40*(4), 425–436. https://doi.org/10.1007/s10803-009-0825-1

Ostrolenk, A., Forgeot d'Arc, B., Jelenic, P., Samson, F., & Mottron, L. (2017). Hyperlexia: Systematic review, neurocognitive modelling, and outcome. *Neuroscience and Biobehavioral Reviews*, *79*, 134–149. https://doi.org/10.1016/j.neubiorev.2017.04.029

Pellecchia, M., Marcus, S. C., Spaulding, C., Seidman, M., Xie, M., Rump, K., Reisinger, E. M., & Mandell, D. S. (2020). Randomized trial of a computer-assisted intervention for children with autism in schools. *Journal of the American Academy of Child & Adolescent Psychiatry*, *59*(3), 373–380. https://doi.org/10.1016/j.jaac.2019.03.029

Pellicano, E., & Burr, D. (2012). When the world becomes 'too real': A Bayesian explanation of autistic perception. *Trends in Cognitive Sciences*, *16*(10), 504–510. https://doi.org/10.1016/j.tics.2012.08.009

Ploog, B. O. (2010). Stimulus overselectivity four decades later: A review of the literature and its implications for current research in autism spectrum disorder. *Journal of Autism and Developmental Disorders*, *40*(11), 1332–1349. https://doi.org/10.1007/s10803-010-0990-2

Qian, N., & Lipkin, R. M. (2011). A learning-style theory for understanding autistic behaviors. *Frontiers in Human Neuroscience*, *5*, 77. https://doi.org/10.3389/fnhum.2011.00077

Reber, A. S., Walkenfeld, F. F., & Hernstadt, R. (1991). Implicit and explicit learning: Individual differences and IQ. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *17*(5), 888–896. https://doi.org/10.1037/0278-7393.17.5.888

Remington, A. M., Swettenham, J. G., & Lavie, N. (2012). Lightening the load: Perceptual load impairs visual detection in typical adults but not in autism. *Journal of Abnormal Psychology*, *121*(2), 544–551. https://doi.org/10.1037/a0027670

Remington, A., & Fairnie, J. (2017). A sound advantage: Increased auditory capacity in autism. *Cognition*, *166*, 459–465. https://doi.org/10.1016/j.cognition.2017.04.002

Remington, A., Hanley, M., O'Brien, S., Riby, D. M., & Swettenham, J. (2019). Implications of capacity in the classroom: Simplifying tasks for autistic children may not be the answer. *Research in Developmental Disabilities*, *85*, 197–204. https://doi.org/10.1016/j.ridd.2018.12.006

Roser, M. E., Aslin, R. N., McKenzie, R., Zahra, D., & Fiser, J. (2015). Enhanced visual statistical learning in adults with autism. *Neuropsychology*, *29*(2), 163–172. https://doi.org/10.1037/neu0000137

Saffran, J. R. (2018). Statistical learning as a window into developmental disabilities. *Journal of Neurodevelopmental Disorders*, *10*(1), 35. https://doi.org/10.1186/s11689-018-9252-y

Samson, F., Mottron, L., Soulières, I., & Zeffiro, T. A. (2012). Enhanced visual functioning in autism: An ALE meta-analysis. *Human Brain Mapping*, *33*(7), 1553–1581. https://doi.org/10.1002/hbm.21307

Schreibman, L., Dawson, G., Stahmer, A. C., Landa, R., Rogers, S. J., McGee, G. G., Kasari, C., Ingersoll, B., Kaiser, A. P., Bruinsma, Y., McNerney, E., Wetherby, A., & Halladay, A. (2015). Naturalistic developmental behavioral interventions: Empirically validated treatments for autism spectrum disorder. *Journal of Autism and Developmental Disorders*, *45*(8), 2411–2428. https://doi.org/10.1007/s10803-015-2407-8

Scott-Van Zeeland, A. A., Dapretto, M., Ghahremani, D. G., Poldrack, R. A., & Bookheimer, S. Y. (2010). Reward processing in autism. *Autism Research*, *3*(2), 53–67. https://doi.org/10.1002/aur.122

Scott-Van Zeeland, A. A., McNealy, K., Wang, A. T., Sigman, M., Bookheimer, S. Y., & Dapretto, M. (2010). No neural evidence of statistical learning during exposure to artificial languages in children with autism spectrum disorders. *Biological Psychiatry*, *68*(4), 345–351. https://doi.org/10.1016/j.biopsych.2010.01.011

Shohamy, D., Myers, C. E., Grossman, S., Sage, J., Gluck, M. A., & Poldrack, R. A. (2004). Cortico-striatal contributions to feedback-based learning: Converging data from neuroimaging and neuropsychology. *Brain: A Journal of Neurology*, *127*(Pt. 4), 851–859. https://doi.org/10.1093/brain/awh100

Smith, T. (2001). Discrete trial training in the treatment of autism. *Focus on Autism and Other Developmental Disabilities*, *16*(2), 86–92. https://doi.org/10.1177/108835760101600204

Soulières, I., Dawson, M., Samson, F., Barbeau, E. B., Sahyoun, C. P., Strangman, G. E., Zeffiro, T. A., & Mottron, L. (2009). Enhanced visual processing contributes to matrix reasoning in autism. *Human Brain Mapping*, *30*(12), 4082–4107. https://doi.org/10.1002/hbm.20831

Soulières, I., Mottron, L., Giguère, G., & Larochelle, S. (2011). Category induction in autism: slower, perhaps different, but certainly possible. *Quarterly Journal of Experimental Psychology*, *64*(2), 311–327. https://doi.org/10.1080/17470218.2010.492994

Tager-Flusberg, H. (1985a). Basic level and superordinate level categorization by autistic, mentally retarded, and normal children. *Journal of Experimental Child Psychology*, *40*(3), 450–469. https://doi.org/10.1016/0022-0965(85)90077-3

Tager-Flusberg, H. (1985b). The conceptual basis for referential word meaning in children with autism. *Child Development*, *56*(5), 1167–1178. https://doi.org/10.2307/1130231

Tillmann, J., Tuomainen, J., & Swettenham, J. (2021). The effect of visual perceptual load on auditory awareness of social vs. non-social stimuli in individuals with autism. *Journal of Autism and Developmental Disorders*, *51*, 1028–1038. https://doi.org/10.1007/s10803-020-04587-0

Ungerer, J. A., & Sigman, M. (1987). Categorization skills and receptive language development in autistic children. *Journal of Autism and Developmental Disorders*, *17*(1), 3–16. https://doi.org/10.1007/BF01487256

Van de Cruys, S., Evers, K., Van der Hallen, R., Van Eylen, L., Boets, B., de-Wit, L., & Wagemans, J. (2014). Precise minds in uncertain worlds: Predictive coding in autism. *Psychological Review*, *121*(4), 649–675. https://doi.org/10.1037/a0037665

Wechsler, D. (2003). *Wechsler intelligence scale for children, 4th edition (WISC–IV)*. Psychological Corporation.

Wechsler, D., Kaplan, E., Fein, D., Kramer, J., Morris, R., Delis, D., & Maerlender, A. (2004). *WISC-IV integrated technical and interpretive manual*. The Psychological Corporation.

Williams, D. L., Minshew, N. J., & Goldstein, G. (2015). Further understanding of complex information processing in verbal adolescents and adults with autism spectrum disorders. *Autism*, *19*(7), 859–867. https://doi.org/10.1177/1362361315586171

Wong, C., Odom, S. L., Hume, K. A., Cox, A. W., Fettig, A., Kucharczyk, S., Brock, M. E., Plavnick, J. B., Fleury, V. P., & Schultz, T. R. (2015). Evidence-based practices for children, youth, and young adults with autism spectrum disorder: A comprehensive review. *Journal of Autism and Developmental Disorders*, *45*(7), 1951–1966. https://doi.org/10.1007/s10803-014-2351-z

Zwart, F. S., Vissers, C. T. W. M., Kessels, R. P. C., & Maes, J. H. R. (2018). Implicit learning seems to come naturally for children with autism, but not for children with specific language impairment: Evidence from behavioral and ERP data. *Autism Research*, *11*(7), 1050–1061. https://doi.org/10.1002/aur.1954

Zwart, F. S., Vissers, C. T. W. M., Kessels, R. P. C., & Maes, J. H. R. (2019). Procedural learning across the lifespan: A systematic review with implications for atypical development. *Journal of Neuropsychology*, *13*(2), 149–182. https://doi.org/10.1111/jnp.12139

Zwart, F. S., Vissers, C. T. W. M., & Maes, J. H. R. (2018). The association between sequence learning on the serial reaction time task and social impairments in autism. *Journal of Autism and Developmental Disorders*, *48*(8), 2692–2700. https://doi.org/10.1007/s10803-018-3529-6

Received August 29, 2019
Revision received April 13, 2021
Accepted April 15, 2021 ■

This document is copyrighted by the American Psychological Association or one of its allied publishers.
Content may be shared at no cost, but any requests to reuse this content in part or whole must go through the American Psychological Association.