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Learning new relational categories by children with autism spectrum disorders, children with typical development and children with intellectual disabilities: effects of comparison and familiarity on systematicity

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Abstract

Background Systematicity principle, used during analogical reasoning, enables building up deeper abstract concepts as part of structure mapping. The purpose of this study was to investigate structure mapping processes that occur during acquisition of new relational categories and to identify the learning patterns and systematicity of children with autism spectrum disorder (ASD) compared with intellectual and developmental disabilities (IDD) and typical development (TD). Comparison effect and level of familiarity were used to investigate structural mapping processes.
Methods Three groups of 24 children participated in the study. Using a computer program, participants were asked to select a perceptual or relational choice based on one or two standards using illustrations depicting new relational categories in various spatial configurations. Known, partially known and unknown illustrations were used in depicting three levels of familiarity.
Results All three groups selected perceptual choices when one standard was available (no comparison). However, when two standards were available, enabling a comparison, children with IDD and TD increased their tendency for selecting abstract relational categories, while children with ASD did not change their preference and continued selecting perceptual choices. Level of familiarity increased selection of relational choices among children with TD and IDD but not among children with ASD.
Conclusions Systematicity principle was evident mostly in the selection of relational choices by children with TD and IDD when the illustrations were known or partially known. Hence, even when an opportunity to compare and to use previously known information was available, structure mapping processes and systematicity were implemented to align information among children TD and IDD but failed to assist the learning of new relational categories among children with ASD.

Keywords autism, comparison effect, familiarity level, intellectual disability, perceptual and relational categories, systematicity principle

Introduction

Language development depends on the child's ability to transfer and generalise knowledge that assist in organising and managing information processing. Children develop commonalities, relate

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sounds to categories, followed by words, structures and linguistic rules that are learned over the years (Dromi 2002). Categorization enables development of complex cognitive structures and minimises cognitive effort by creating similarities using various characteristics formed into commonalities (Gentner 2010).

Language development allows enrichment of the cognitive system by creating numerous complex connections between different knowledge-based structures, whereas developed cognitive systems allow learning of abstract and complex concepts (Gentner 2010; Gentner *et al.* 2011; Green *et al.* 2014.(These language–cognition relationships unwrap themselves via relational shift, a developmental stage that occurs among children around 4–6 years old, with the maturation of structure mapping processes. Structure mapping is a core cognitive process during which different structures of knowledge are aligned and compared and relational similarities are identified and transferred to form new coherent concepts. According to systematicity principle, the formation of coherent structures occurs through mapping similarities that prioritise creation of structures with complex internal connections, rather than through basic external connections (Gentner 1983, 2005, 2010; Gentner & Smith 2012). For example, perceptual categories are concrete, surface-based constructs, such as the comparison between two similar animals to formulate a connection that identifies them both as dogs. This mapping principle is based on the particular physical dimensions of the objects. In contrast, relational categories, such as spatial concepts, are abstract constructs composed of interactions between structures that share common spatial relations. The concept ‘near’ encompasses interactions between two objects or people by proximity. As such, ‘present’ is a concept that may differ from the physical dimension of ‘box’. Mapping in these cases involves using systematicity principle that enables deep relational connections between objects and between object and its context. Thus, structure mapping bootstraps cognitive and language development into new and sophisticated levels of usage, building higher functions such as symbolic and social understanding, conceptual categorization, metaphors and analogical reasoning (e.g. Gentner 2010; Landau Mejer & Keefer 2010).

Comparison is a one of the most basic cognitive processes. In low levels of information processing, comparisons within the physical realms allow to perceive boundaries of forms by differentiating contrasts of shades. Within the cognitive realms, comparisons are fundamental processes of categorization. In high levels of information processing such as an analogical reasoning, and social learning, comparisons enable structure mapping and emergence of the self (e.g. social comparison theory; Festinger 1954). Comparison studies demonstrated that the process facilitates deep structural analysations between comparison stimuli. For example, Gentner & Namy (1999) presented new names for illustrations (e.g. a bike), followed by presentation of two choices, one illustration presenting a perceptual resemblance (e.g. glasses) and another a relational resemblance (e.g. skateboard). When participants were presented with one original, they preferred the perceptual resemblance (glasses), but when two originals (comparison condition) were presented (bike and tricycle), the participants highly preferred conceptual resemblance (skateboard). This comparison effect, replicated in other studies (Gentner & Toupin 1986; Gentner & Markman 1994), suggests that providing opportunities for comparison facilitates analysations through systematicity principle.

Comparison can be performed between two novel objects and between known and novel ones. One of the main goals of categorization is to determine whether the presented object is similar to a known category, thus determining the level of familiarity between the new, unknown object and the known one. Highly familiar objects improve the accuracy of categorization, which enable the processing of information needed for addressing more abstract aspects of the objects required for determining conceptual relations. In contrast, categorization and identification of partially familiar and unfamiliar objects will heavily rely upon concrete and physical aspects, thus resulting in a tendency to lean on basic perceptual features of the objects, especially within short-time decision-making framework.

Challenges in language and communication are core features of autism spectrum disorder (ASD) (Boucher 2009). ASD is a neurodevelopmental disorder characterised by impairments in communication, language and social interactions, along with restricted patterns of behaviours, activities and areas of interests (American Psychiatric Association (APA) 2013). Studies examining language and communication of children with ASD identified difficulties in formation and understanding language and social-based rules (e.g. Kjelgaard & Tager-Flusberg 2001; Zelazo *et al.* 2002), generalisation and transfer between settings and less reliance on prior knowledge (e.g. Brown & Bebko 2012; Pellicano & Burr 2012).

A deeper understanding of the difficulties and differences demonstrated in acquiring concepts and categories may enhance understanding of learning processes, which could account for some of the observed symptoms among individuals with ASD (Klinger & Dawson 2001; Plaisted 2001; Gastgeb *et al.* 2006, 2011a). For example, individuals with ASD were able to learn typical categories over time, but atypical categories remained difficult for them (Gastgeb *et al.* 2006). However, when provided with explicit instructions, they demonstrate an increased ability to identify information even when ambiguous (Sobel *et al.* 2005). Studies demonstrated that when provided with specific instruction, complex and global processing were enabled (Caron *et al.* 2006; Mottron *et al.* 1999). Such results were evident even among individuals with autism and intellectual disabilities, whereas they were able to generalise and maintain the newly acquired cognitive strategy (Bock 1994). These findings may suggest that individuals with ASD that demonstrate a tendency to engage in perceptual, detailed-focused processing might be pursuing it as a cognitive style (Tsatsanis *et al.* 2011) rather than a deficit (Happé & Frith 2006). This cognitive style, might, therefore, increase the possibility of pursuing perceptual rather than relational processing (e.g. Green *et al.* 2014; Happé & Frith 2006). This bias could perhaps lead towards a disadvantage when confronted with abstract situations resulting in a tendency for inflexibility and perseveration (Minshew *et al.* 2002; Green *et al.* 2014). Hence, while individuals with ASD are capable of successfully classifying information based on concrete perceptual characteristics, they might find it difficult to draw similarities when characteristics are more abstract or conceptual in nature (Shulman *et al.* 1995; Plaisted 2000; Gastgeb *et al.* 2006) as evident, for example, in categorization tasks, required for creating prototypes (Klinger *et al.* 2006; Gastgeb *et al.* 2011a; Gastgeb *et al.* 2011b) or organisation of encoded words by semantic clustering especially among individual with ASD who have lower intellectual functioning (Cheung *et al.* 2010).

It might be that cognitive system of individuals with ASD find it difficult to deal with tasks that require creation of structural similarity based on complex internal connections and application of the systematicity principle (e.g. Plaisted 2000; Gastgeb *et al.* 2006, 2011a; Klinger *et al.* 2006). For example, when presented with a task involving analogical reasoning and systematicity, children with ASD who have high cognitive abilities demonstrated intact abilities in selecting conceptual choices compared with children with typical development (TD) (Hetzroni & Shalahevich 2018). However, when a perceptual distractor was introduced to the target stimuli, they preferred to choose perceptually similar objects, compared with children with TD. Yet studies have demonstrated that children with ASD who have high cognitive abilities have capabilities for categorising information while formulating similarities when compared with children with TD (e.g. Mayes & Calhoun 2008; Hetzroni & Shalahevich 2013). The use of social and non-social abstract analogical reasoning has also been found to be intact among individuals with ASD with and without intellectual disabilities (e.g. Morsanyi & Holyoak 2010; Green *et al.* 2014, 2017). It was therefore the aim of this study to further understand the basic foundations of information processing during the formation of novel concepts.

In this study, children with ASD without intellectual disabilities were selected to participate in an investigation aimed to identify new concepts using spatial analogies in comparison with more concrete perceptual ones. The application of new relational categories, derived from the Christie & Gentner (2010) study, was to investigate an important linguistic aspect of relational nouns that are abstract in nature, distant from their perceptual features. The present study included elementary school-aged children to reflect a subsequent linguistic developmental stage of learning relational categories (Christie & Gentner 2010). Hence, participants were recruited based on their matched language abilities. Comparisons were used to enhance and incorporate explicit instruction that could increase the possibility of learning new abstract similarities (Green *et al.* 2014, 2017). The method used for the study required participants to draw comparisons between the original and the target illustrations using a matching-to-sample task, a learning strategy widely used to teach individuals with ASD (e.g. Dube *et al*. 2016; Farber *et al*. 2016; Hetzroni & Shalahevich 2018).

The purpose of this study was to examine structure mapping that occurred during acquisition of new relational categories among children with ASD without intellectual disabilities, compared with children with TD and children with intellectual and developmental disabilities (IDD) with no ASD. Two research questions were derived out of this purpose: (1) whether providing an opportunity for comparing graphic representations (within comparison) would assist in learning new relational categories among the three groups and (2) would providing graphic representations that denominate familiar characteristics increase the ability to elicit new relational categories while using deeper analogical reasoning as suggested by systematicity principle across the three groups? The hypothesis was that although groups were matched based on their language abilities, individuals with ASD might differ in their use of structure mapping and systematicity principle under different conditions and that comparisons would enhance deeper structure mapping, among the groups of children with TD and IDD but less with ASD. Familiarity level would assist in identifying the new relational categories.

Method

Participants

Children with ASD (ages 5–8), IDD (ages 7–16) and TD (ages 5–6) participated in the study. Children were recruited using parent letters sent through schools. The 72 children, 24 in each group, were recruited based on their matched receptive language age (described in the succeeding texts). Diagnosis for the group of children with IDD without ASD or any other co-morbid conditions was obtained from the psychological education services or the National Services for People with IDD in accordance with the *Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition* (American Psychiatric Association (APA) 2013). In addition to the *Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition* (American Psychiatric Association (APA) 2013) diagnosis, children with ASD were assessed using the Childhood Autism Rating Scale Second Edition High Functioning Version (CARS-2-HF) using 27.5 as the cut-off score indicating an ASD diagnosis (Vaughan 2011). Intelligence level was obtained from the psychological education services, their school records and block design sub-test of Wechsler's IQ test. Receptive language was assessed using Preschool Language Scale Fourth Edition (PLS-4) sub-test (Zimmerman *et al*. 2002) and the receptive vocabulary sub-tests of the Wechsler's IQ test (WPPSI-III; Wechsler 2002). All children were speaking Hebrew as their first language. Hebrew versions of the tests were used across the study. Table 1 presents the demographic characteristics of the three groups.

Materials

Relational language expansion graphic symbol application program

The software created for this study was adapted from Christie & Gentner (2010), with modifications made to examine the variables: (1) within comparison conditions and (2) levels of familiarity. The software included two sets of 13 screens with graphic illustrations depicting new relational formations (see flow chart and illustrations in Fig. 1). Each screen depicted 2–3 colourful illustrations placed in various spatial and relational configurations. The illustrations depicted seven sets of known (culturally familiar animals), three sets of partially known (real animals from other continents, unknown to the age group) or three sets of unknown (invented) creatures representing three levels of familiarity. Familiarity level was determined by three experts and by five children with TD.

In the first set (Fig. 1a), each screen consisted of one original symbol depicting illustrations in various relational configurations (e.g. two koalas mirroring each other), followed by two target symbols providing a relational or a perceptual choice. In the relational choice, the illustrations represented the same relational category with different symbols (e.g. two warthogs mirroring each other), while in the perceptual configuration, one part of the configuration looked like the original one (e.g. one goat positioned in a similar position over one koala

Table 1 Demographic data for participants across the three groups

			TD	IDD	ASD
Gender		Male	10	15	18
		Female	14	9	6
Age (years)		Mean (SD)	5.63 (0.27)	11.88 (2.29)	6.57 (0.87)
		Range	1	8.83	3.09
Verbal intelligence	Receptive language (raw data†)	Mean (SD)	60.63 (0.82)	59.88 (0.8)	60.12 (0.89)
		Range	3	2	3
	Receptive vocabulary (raw data†)	Mean (SD)	31.38 (2.18)	30.88 (1.26)	31.25 (1.6)
		Range	9	5	6
Non-verbal intelligence	Block design (raw data†)	Mean (SD)	29.92 (1.5)	25.42 (2.39)	30.58 (3.30)
		Range	6	8	10
Screening ASD	CARS-2	Mean (SD)	33.1 (5.3)		
		Range	18		

†Age of children with IDD required use of raw data.
ASD, autism spectrum disorder; IDD, intellectual and developmental disabilities; TD, typical development; CARS-2, Childhood Autism Rating Scale Second Edition.

positioned similarly to the original symbol). Each screen included a recorded voice stating 'This is Nucan (various invented words for each relational configuration). Can you say Nucan?' Following the presentation of the original illustration, two choices appeared in addition to the original, accompanied with 'Can you find another Nucan?' The participant was instructed to select one of the two target choices presented on the bottom of the screen, a relational choice or a perceptual choice, using a matching-to-sample procedure (e.g. Hetzroni & Shalahevich 2018).

The second set (Fig. 1b) included 13 screens with two original graphical illustrations to enable comparison, followed by the two relational and perceptual choices, displayed alongside the originals. In this set, each screen included a recorded voice stating 'This is Zuban. Here is another Zuban. Can you say Zuban? Can you see why these two are Zuban?' Responses were not requested. After introducing the two original symbols (e.g. white over black cats/dogs), the two target choices appeared, and a recorded voice stated 'Can you find another Zuban?' (e.g. white camel over black camel as a relational choice and black cat and dog in diagonal position as a perceptual choice). Two training screens were added to demonstrate the requirement. Validity tests conducted among experts and children between ages 3–7 determined the appropriateness of the level of familiarity and the software. The order of the screens and the placement of the target representations appeared in a random order.

Procedure

After receiving approval from ethics committees and getting approval letters from parents, children were assessed for inclusion criteria. In this study, each child was tested separately in a quiet room. In the beginning of the session, children were asked to participate in a selection game, in which they were asked to choose one of the two target symbols. The child sat by a portable computer and manipulated the application independently using a mouse. The task lasted 10–15 min. The session lasted 30–40 min. No feedback was provided regarding the selection. Participants received stickers as a token of appreciation at the end of the experiment. All selections were tallied on a computer log and recorded. Selection preferences were scored as 1 for relational configurations and 0 for the selection of perceptual configurations.

Data analysis

In order to test our first hypothesis, data analyses were conducted to examine differences between the three groups across the two conditions (within comparisons) and the familiarity levels. A one-way repeated measures multivariate analysis of variance (MANOVA) was conducted in order to reveal main

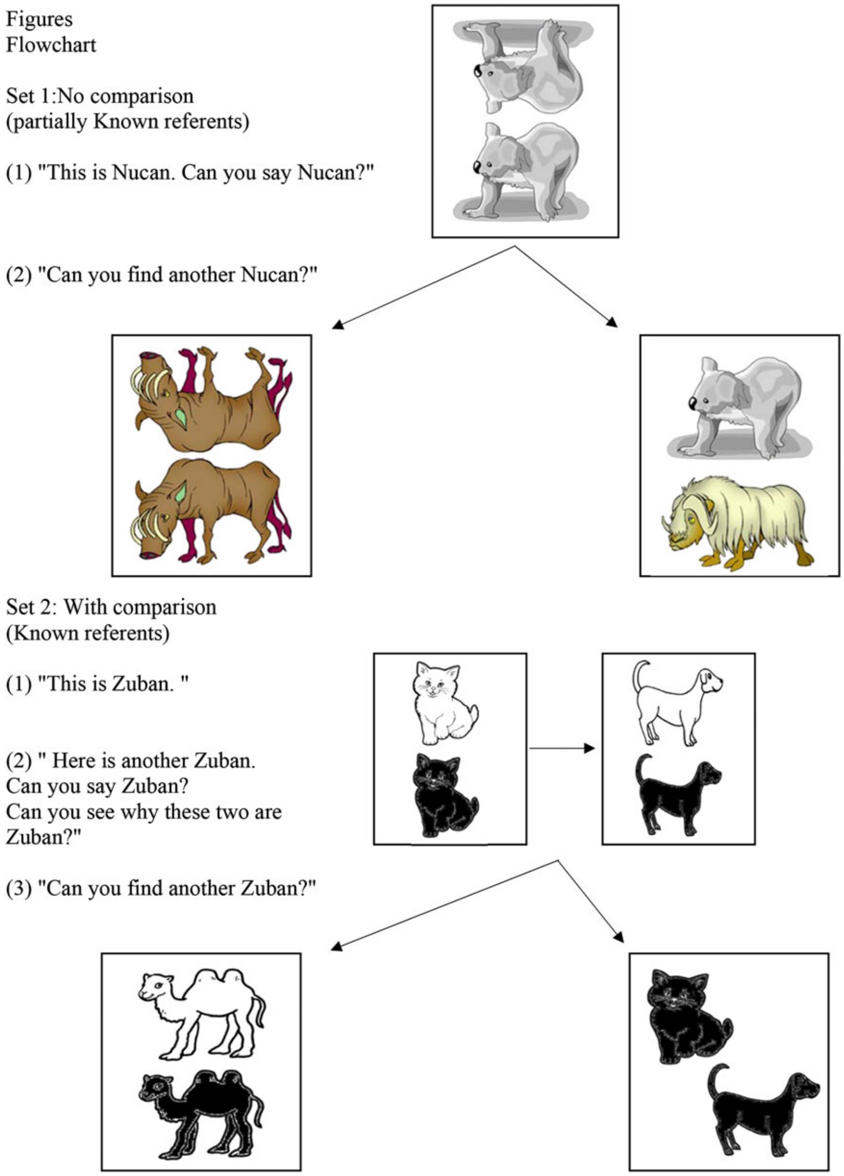

Figure 1 Flow chart of relational category task with (bottom layout) and without (above layout) comparison with partially and known symbols depicting new relational configurations (greyscale 4.53 × 7.86 in.; 96 × 96 dpi). [Colour figure can be viewed at wileyonlinelibrary.com]

effects and interactions of conditions and familiarity levels within group variable. In addition, main effect of groups between group variable, including an interaction between groups, conditions and familiarity levels, was evaluated. One-way repeated measures MANOVA was further conducted for groups and conditions separately in order to detect the origin of the main effects of condition and familiarity levels, followed by Bonferroni correction tests to investigate the interactions between groups, conditions and familiarity levels. In order to investigate possible influence of receptive language and cognitive profile on matching scores in each condition separately, a one-way multivariate analysis of covariance was implemented.

One-way analysis of variance with gender as independent and total mean matching score as dependent variables, conducted to investigate possible influences of gender, revealed no main effect for gender ($P = 0.84$). In addition, one-way analysis of covariance with groups as independent and total mean matching score as dependent variables, conducted to investigate possible influences of age as a covariant, revealed no main effect for age ($P = 0.604$). Hence, there were no further analyses with gender and age as covariates.

In addition, a one-way MANOVA with groups as independent and receptive language (PLS-4), receptive vocabulary (WPPSI-III) and block design tests scores as dependent variables revealed significant differences between groups using the results from the PLS-4 ($F_{2, 69} = 4.94$, $MSE = 0.708$, $P = 0.01$, $\eta^2 = 0.125$) and the block design sub-test ($F_{2, 69} = 33.07$, $MSE = 5.73$, $P < 0.001$, $\eta^2 = 0.49$). However, no significant difference was found between groups in receptive vocabulary test using the WPPSI-III subtest. Bonferroni correction test revealed that the significant differences in PLS-4 were found only between TD and IDD groups ($P = 0.009$) and TD (M = 60.63, SD = 0.82), which was higher than IDD (M = 59.88, SD = 0.79). In block design sub-test, significant differences were found between TD and IDD groups ($P < 0.001$) and between ASD and IDD groups ($P < 0.001$). TD (M = 29.92.63, SD = 1.5) and ASD (M = 30.58, SD = 3.03) were higher than IDD (M = 25.42, SD = 2.39).

Results

One-way repeated measures MANOVA ($3 \times 2 \times 3$) conducted to compare the main effects of group, condition and familiarity level on matching scores demonstrated main effect for group, $F_{2, 69} = 9.75$, $MSE = 0.29$, $P < 0.001$, $\eta^2 = 0.220$, main effect for condition, $F_{1, 69} = 138.97$, $MSE = 0.083$, $P < 0.001$, $\eta^2 = 0.668$, and main effect for level of familiarity, $F_{2, 138} = 23.274$, $MSE = 0.019$, $P < 0.001$, $\eta^2 = 0.252$. Significant interactions were found between group and condition, $F_{2, 69} = 23.355$, $MSE = 0.083$, $P < 0.001$, $\eta^2 = 0.404$, between condition and familiarity levels, $F_{2, 138} = 7.513$, $MSE = 0.027$, $P < 0.001$, $\eta^2 = 0.098$, between group and familiarity level, $F_{4, 138} = 7.5$, $MSE = 0.019$, $P < 0.001$, $\eta^2 = 0.18$, and between group, condition and familiarity level, $F_{4, 138} = 3.567$, $MSE = 0.027$, $P = 0.008$, $\eta^2 = 0.094$.

Analyses conducted for each group separately demonstrated significant difference between conditions, $F_{1, 23} = 93.646$, $MSE = 0.105$, $P < 0.001$, $\eta^2 = 0.8$, familiarity level, $F_{2, 46} = 19.122$, $MSE = 0.032$, $P < 0.001$, $\eta^2 = 0.454$, and significant interaction between condition and familiarity level, $F_{2, 46} = 6.509$, $MSE = 0.045$, $P = 0.003$, $\eta^2 = 0.221$, in the TD group, and significant difference between conditions, $F_{1, 23} = 54.211$, $MSE = 0.1$, $P < 0.001$, $\eta^2 = 0.702$, familiarity level, $F_{2, 46} = 6.826$, $MSE = 0.019$, $P = 0.003$, $\eta^2 = 0.229$, and significant interaction between condition and familiarity level, $F_{2, 46} = 3.82$, $MSE = 0.026$, $P = 0.029$, $\eta^2 = 0.142$, in the IDD group. However, no significant differences between conditions ($P = 0.057$) and between familiarity levels ($P = 0.726$) were found in the ASD group.

Analyses conducted for each condition separately revealed no significant difference between the groups in the first condition ($P = 0.278$), not with familiar, partially familiar nor in the unfamiliar illustrations. However, in the second condition, analysis revealed a significant difference between the groups, $F_{2, 69} = 31.525$, $MSE = 0.073$, $P < 0.001$, $\eta^2 = 0.477$ (Fig. 2). The interactions between familiarity levels and group in the second condition analysed with Bonferroni correction test revealed that when familiarity level was high, the mean percentage of matching scores was significantly higher in TD 77% than IDD 38% and ASD 16% ($P < 0.001$) and in IDD than in ASD ($P = 0.015$). In the partially familiar level, the mean percentage of matching scores was significantly higher in TD 76% than IDD 50% ($P < 0.014$) and ASD 17% ($P < 0.001$) and in IDD than in ASD ($P < 0.001$). In the unfamiliar level the mean percentage of matching scores was significantly higher only in TD 44% than ASD 15% ($P = 0.01$) (Fig. 3).

One-way multivariate analysis of covariance with groups as independent and condition as dependent variables, conducted to investigate possible influences of PLS-4 and block design subtests as covariates, revealed main effect for group only in the second condition, $F_{2, 67} = 26.17$, $MSE = 0.64$, $P < 0.001$, $\eta^2 = 0.44$. Bonferroni correction test revealed significant differences only in the second condition between TD and ASD groups, with both tests as covariates ($P < 0.001$), with TD (M = 0.69, SD = 0.2) higher than ASD (M = 0.16, SD = 0.31).

Discussion

Analogical reasoning is an important mechanism for understanding language, communication and

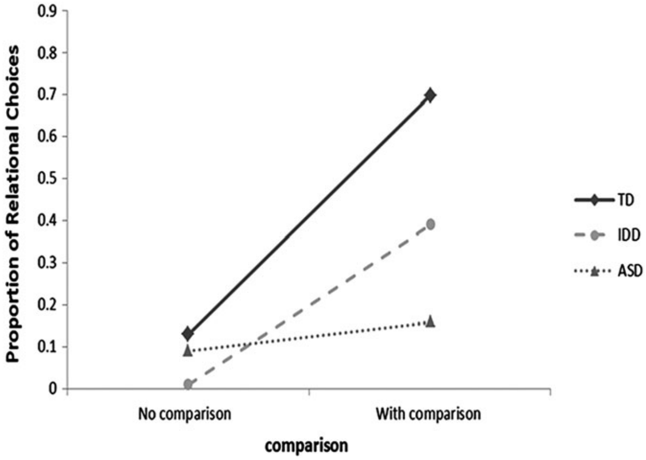

Figure 2 Relational choices among groups by level of comparison. ASD, autism spectrum disorder; IDD, intellectual and developmental disabilities; TD, typical development (greyscale 4.53 × 3.12 in.; 240 × 240 dpi).

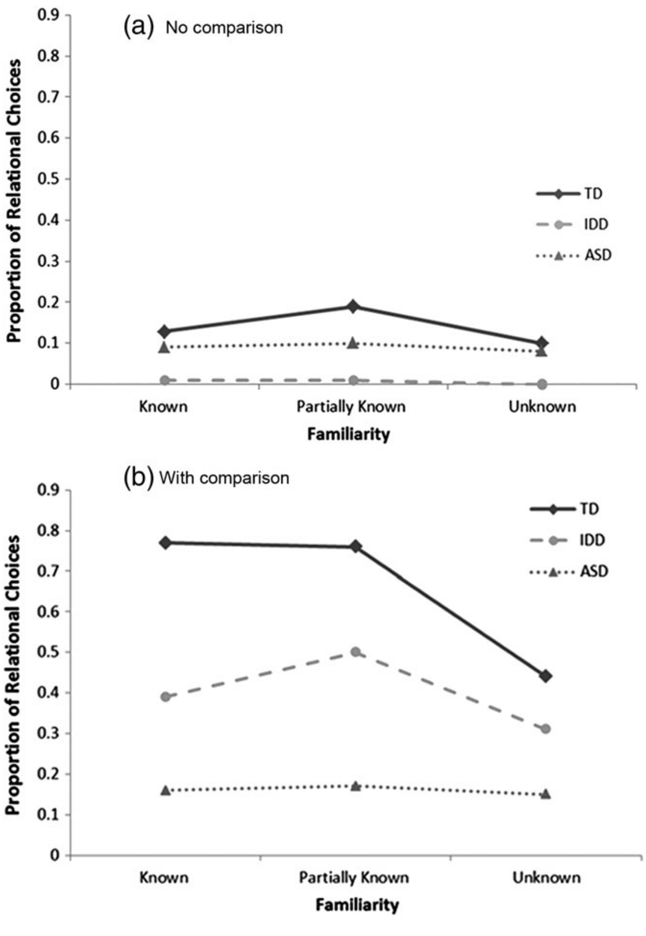

Figure 3 Relational choices among groups by familiarity level with (bottom layout) and without (above layout) comparison. ASD, autism spectrum disorder; IDD, intellectual and developmental disabilities; TD, typical development (greyscale 4.53 × 6.3 in.; 300 × 300 dpi).

social situations (e.g. Gentner 2010; Cheung *et al.* 2010). The use of analogical reasoning and the presence of systematicity principle were investigated using comparison effect, familiarity level in a matching-to-sample task, aimed for learning new relational categories in children with ASD. Previous studies demonstrate that children with ASD were able to sort and match symbols using this learning strategy (e.g. Dube *et al.* 2016; Farber *et al.* 2016; Hetzroni & Shalahevich 2018). In this study, children were asked to identify new concepts based on one or two representations. The second representation (comparison effect) was added to increase the opportunity for comparison and assist in building similarities based on deeper abstract characteristics. Children with ASD demonstrate strengths in non-verbal reasoning and in categorising tasks that support detailed characteristics (e.g. Mayes & Calhoun 2008) but may have difficulties in structure mapping to identify abstract similarities.

Analogical reasoning and systematicity

Results of the study demonstrate that when children with TD, IDD and ASD were presented with one original, all groups demonstrated similar results, with a strong preference for selecting a choice based on perceptual representation rather than on relational choice and did not use structure mapping processes for deeper relational connections. However, when presented with two originals, the groups of children with TD and IDD demonstrated an increase in their tendency to extend the choices based on relational matching, with an increase proportion of relational choices of 0.57 for children with TD and 0.38 for children with IDD, in comparison with only 0.07 for children with ASD. Results support previous findings demonstrating that for children with TD, the opportunity to compare between two originals significantly increased selections based on relational structure (Gentner & Namy 1999; Christie & Gentner 2010). When presented with symbolic representations that support basic linguistic opportunities to compare, structure mapping was used to form new relational categories using systematicity for gaining deeper analogical reasoning (Gentner 2010). Comparisons applied through structure mapping served to highlight deeper common relational features, which were previously hidden, building up new relational categories. Results provide evidence that the two types of selection, perceptual and conceptual, occur simultaneously in the process of concept acquisition. These processes occur from the first years of the children's life (Mandler 2000). Over time, these processes show a gradual learning curve, which begins by identifying the perceptual structures and connections, developing through comparison processes, to the identification of conceptual structures and connections (Namy & Gentner 2002; Cimipian & Markman 2005; Green *et al.* 2014). Accumulated knowledge, and complex symbolic understanding, build alongside the development of the cognitive system over time.

In our study, children with ASD demonstrated a similar performance style across both conditions, showing preference for extending concepts based on concrete matching, using perceptual characteristics rather than a common relational structure. Participants with ASD did not benefit from the opportunity provided for in-depth analysis of the connections between the representations that were presented to them through comparison processes. Children with ASD continued to base their preferences on perceptual characteristics even in the comparison condition. Moreover, in contrast to the participants with TD and IDD, who possibly benefited from the opportunity given to them to apply accumulated knowledge (familiarity) for the development of relational categories when provided with the opportunity to compare (Gentner 2010), children with ASD demonstrated a similar perceptual trend in both conditions. These results support previous studies demonstrating a consistent tendency to select based on perceptual preferences even when comparisons were available for children with ASD (e.g. Plaisted 2001; Gastgeb *et al.* 2006, 2011a, 2011b; Klinger *et al.* 2006; van der Hallen *et al.* 2015).

While the groups of children with IDD and TD were able to change their selection, based on the strategy that provided additional knowledge gained through comparison, children with ASD did not change their original selections. Thus, the perceptual tendency that the children with ASD demonstrated remained consistent regardless of the new information is similar to previous studies (Guy *et al.* 2016; Heaton & Freeth 2016; Simmons *et al.* 2009; van der Hallen *et al.* 2015). These results are consistent with the assumption that this bias could relate to the tendency associated with inflexibility and perseveration (e.g. Minshew *et al.* 2002). Hence, even when presented with the ability to compare, participants with ASD did not use systematicity to identify the deeper abstract similarity and continued selecting based on perceptual characteristics.

It has been suggested that grouping information and using it for determining new relational categories would occur with time and explicit effort, suggesting an inherent tendency to select based on perceptual characteristics rather than a deeper conceptual one (van der Hallen *et al.* 2015). With explicit instruction, children with ASD were capable of identifying abstract similarities using analogical reasoning (Green *et al.* 2014; Farber *et al.* 2016) and that these abilities were correlated with age. Yet children with ASD who were selecting conceptual items similarly to their TD peers shift their selection to perceptual similarity when provided with a perceptual distractor (Hetzroni & Shalahevich 2018). Hence, further studies should investigate the use of explicit strategies under various conditions.

Familiarity

When presented with one original, children from all three groups demonstrated similar preferences in selecting based on perceptual representation regardless of the level of familiarity. Hence, the tendency to attach a new label to familiar illustrations was evident across all groups. However, when two originals were presented, familiarity played a role in selection for the TD and the IDD groups, whereas when the symbols were known or partially known, they were able to identify the abstract characteristics depicting new relational categories and selected them more often. This modification was not as clear when unknown illustrations were presented, as the children in the IDD and TD groups maintained a partial tendency to select based on perceptual similarity. Results demonstrate that when children saw two originals for each new relational category, the knowledge based on the familiarity level affected the performance of children with TD and IDD but not the performance of children with ASD. Hence, familiarity assisted in the application of systematicity principle for preferring relational matching for children with TD and IDD, while for the group of children with ASD, level of familiarity did not modify the preference for extending concepts on the basis of perceptual matching across both conditions. Thus, children with TD and IDD were able to add knowledge to the new comparison presented to them to increase a deeper level of analogical reasoning (Horton & Markman 1980; Gentner 2010). Individuals with ASD might be characterised by atypical structure mapping process style, a diversity that cannot be explained by the general level of cognitive function or by developmental delay, showing a tendency for perceptual selection in the process of concept acquisition, without producing significant benefits from the opportunity to compare and use different knowledge-based structures, for analysing connections to create conceptual maps.

Limitations and future research

It is important to note that although results demonstrated difficulties to use systematicity principle in the process of analogical reasoning among children ages 5–8 with ASD, this study does not compare this capability across a wider age and cognitive range. In light of previous study findings (e.g. Green *et al.* 2014), further studies should investigate the role of age and more explicit instruction on the learning of new relational categories, especially in light of their importance to the development of language and social abilities. Further studies could also benefit from examining structure mapping processes across different levels of abstract information and across acquisition of different levels of abstract knowledge, especially for individuals with lower cognitive abilities who might benefit from graphical symbols.

Ethical approval

All procedures performed involving human participants were in accordance with the ethical standards of the institutional and the national research committees.

Conflict of interest

Both authors declare that there is no conflict of interest.

References

American Psychiatric Association (APA) (2013) *Diagnostic and Statistical Manual of Mental Disorders (DSM-5)*. APA, Washington, DC.

Bock M. A. (1994) Acquisition, maintenance, and generalization of a categorization strategy by children with autism. *Journal of Autism and Developmental Disorders* **1**, 39–51.

Boucher J. (2009) *The Autistic Spectrum: Characteristics, Causes and Practical Issues*. Sage, London.

Brown S. M. & Bebko J. M. (2012) Generalization, overselectivity, and discrimination in the autism phenotype: a review. *Research in Autism Spectrum Disorders* **6**, 733–40.

Caron M. J., Mottron L., Berthiaume C. & Dawson M. (2006) Cognitive mechanisms, specificity and neural underpinnings of visuospatial peaks in autism. *Brain* **129**, 1789–802.

Cheung M., Chan A. S., Sze S. L., Leung W. W. & Yee T. C. (2010) Verbal memory deficits in relation to organization strategy in high- and low-functioning autistic children. *Research in Autism Spectrum Disorders* **4**, 764–71.

Christie S. & Gentner D. (2010) Where hypotheses come from: learning new relations by structural alignment. *Journal of Cognition and Development* **11**, 356–73.

Cimipian A. & Markman E. M. (2005) The absence of a shape bias in children's word learning. *Developmental Psychology* **24**, 1003–19.

Dromi E. (2002) Stages in the acquisition of Hebrew as a mother tongue. In: *Language, Learning and Literacy in the Preschool Years* (eds P. Klein & D. Givon), pp. 9–41. Ramot, Tel Aviv, Israel. (Hebrew).

Dube W. V., Farber R. S., Mueller M. R., Grant E., Lorin L. & Deutsch C. K. (2016) Stimulus overselectivity in autism, Down syndrome, and typical development. *American Journal on Intellectual and Developmental Disabilities* **121**, 219–35.

Farber R. S., Dube W. V. & Dickson C. A. (2016) A sorting-to-matching method to teach compound matching to sample. *Journal of Applied Behavior Analysis* **49**, 294–307.

Festinger L. (1954) A theory of social comparison process. *Human Relations* **7**, 117–40.

Gastgeb H. Z., Dundas E. M., Minshew N. J. *et al.* (2011a) Category formation in autism: can individuals with autism form categories and prototypes of dot patterns? *Journal of Autism and Developmental Disorders* **42**, 1694–704.

Gastgeb H. Z., Strauss M. S. & Minshew N. J. (2006) Do individuals with autism process categories differently? The effect of typicality and development. *Child Development* **77**, 1717–29.

Gastgeb H. Z., Wilkinson D. A., Minshew N. J. *et al.* (2011b) Can individuals with autism abstract prototypes of natural faces? *Journal of Autism and Developmental Disorders* **41**, 1609–18.

Gentner D. (1983) Structure-mapping: a theoretical framework for analogy. *Cognitive Science* **7**, 155–70.

Gentner D. (2005) The development of relational category knowledge. In: *Building Object Categories in Developmental Time* (eds L. Gershkoff-Stowe & D. H. Rakison), pp. 245–75. Erlbaum, Hillsdale, NJ.

Gentner D. (2010) Bootstrapping the mind: analogical processes and symbol systems. *Cognitive Science* **34**, 752–75.

Gentner D., Anggoro F. K. & Klibanoff R. S. (2011) Structure mapping and relational language support children's learning of relational categories. *Child Development* **82**, 1173–88.

Gentner D. & Markman A. B. (1994) Structural alignment in comparison: no difference without similarity. *Psychological Science* **5**, 152–8.

Gentner D. & Namy L. L. (1999) Comparison in the development of categories. *Cognitive Development* **14**, 487–513.

Gentner D. & Smith L. (2012) Analogical reasoning. In: *Encyclopedia of Human Behavior* (ed. V. S. Ramachandran), 2nd edn, pp. 130–6. Elsevier, Oxford, UK.

Gentner D. & Toupin C. (1986) Systematicity and surface similarity in the development of analogy. *Cognitive Science* **10**, 277–300.

Green A. E., Kenworthy L., Gallagher N. M. *et al.* (2017) Social analogical reasoning in school-aged children with autism spectrum disorder and typically developing peers. *Autism* **21**, 403–11.

Green A. E., Kenworthy L., Mosner M. G. *et al.* (2014) Abstract analogical reasoning in high-functioning children with autism spectrum disorders. *Autism Research* **7**, 677–86.

Guy J., Mottron L., Berthiaume C. *et al.* (2016) A developmental perspective of global and local visual processes in autism spectrum disorder. *Journal of Autism and Developmental Disorders*, 1–5.

Happé F. & Frith U. (2006) The weak coherence account: detail-focused cognitive style in autism spectrum disorders. *Journal of Autism and Developmental Disorders* **36**, 5–25.

Heaton T. J. & Freeth M. (2016) Reduced visual exploration when viewing photographic scenes in individuals with autism spectrum disorder. *Journal of Abnormal Psychology* **125**, 399–411.

Hetzroni O. & Shalahevich K. (2013) *Conceptual Categorization in Autism Spectrum Disorder: Enhanced Perceptual Processing or Reduced Detection of Abstract Similarity, Presented at International Association for the Scientific Study of Intellectual and Developmental Disabilities (IASSIDD) Asia-Pacific Conference, Tokyo, Japan, 2013*. Wiley Periodicals, Inc., Hoboken, NJ.

Hetzroni O. E. & Shalahevich K. (2018) Structure mapping in autism spectrum disorder: levels of information processing and relations to executive functions. *Journal of Autism and Developmental Disorders* **48**, 824–33.

Horton M. S. & Markman E. M. (1980) Developmental differences in the acquisition of basic and superordinate categories. *Child Development* **51**, 708–19.

Kjelgaard M. M. & Tager-Flusberg H. (2001) An investigation of language impairment in autism: implications for genetic subgroups. *Language & Cognitive Processes* **16**, 287–308.

Klinger L. G. & Dawson G. (2001) Prototype formation in autism. *Development and Psychopathology* **13**, 111–24.

Klinger L. G., Klinger M. R. & Pohlig R. L. (2006) Implicit learning impairments in autism spectrum disorders: implications for treatment. In: *New Developments in Autism: The Future Is Today* (eds J. M. Perez, P. M. Gonzalez, M. L. Comi & C. Nieto), pp. 75–102. Kingsley Press, London.

Landau M. J., Meier B. P. & Keefer L. A. (2010) A metaphor-enriched social cognition. *Psychological Bulletin* **136**, 1045–67.

Mandler J. M. (2000) Perceptual and conceptual processes in infancy. *Journal of Cognition and Development* **1**, 3–6.

Mayes S. D. & Calhoun S. L. (2008) WISC-IV and WIAT-II profiles in children with high-functioning autism. *Journal of Autism and Developmental Disorders* **38**, 428–39.

Minshew N. J., Meyer J. & Goldstein G. (2002) Abstract reasoning in autism: a dissociation between concept formation and concept identification. *Neuropsychology* **16**, 327–34.

Morsanyi K. & Holyoak K. J. (2010) Analogical reasoning ability in autistic and typically developing children. *Developmental Science* **13**, 578–87.

Mottron L., Burack J. A., Stauder J. E. A. & Robaey P. (1999) Perceptual processing among high-functioning persons with autism. *Journal of Child Psychology and Psychiatry and Allied Disciplines* Volume **40**, 203–11.

Namy L. L. & Gentner D. (2002) Making a silk purse out of two sow's ears: young children's use of comparison in category learning. *Journal of Experimental Psychology: General* **131**, 5–15.

Pellicano E. & Burr D. (2012) When the world becomes 'too real': a Bayesian explanation of autistic perception. *Trends in Cognitive Sciences* **16**, 504–10.

Plaisted K. C. (2000) Aspects of autism that theory of mind cannot explain. In: *Understanding Other Minds: Perspectives from Developmental Cognitive Neuroscience* (eds S. Baron-Cohen, H. Tager-Flusberg & D. J. Cohen), pp 224–50. Oxford University Press, New York.

Plaisted K. (2001) Reduced generalization in autism: an alternative to weak central coherence. In: *The Development of Autism: Perspectives from Theory and Research* (eds J. A. Burack, T. Charman, N. Yirmiya & P. R. Zelazo), pp. 149–69. Erlbaum, Hillsdale, NJ.

Simmons D. R., Robertson A. E., McKay L. S. *et al.* (2009) Vision in autism spectrum disorders. *Vision Research* **49**, 2705–39.

Shulman C., Yirmiya N. & Greenbaum C. W. (1995) From categorization to classification: a comparison among individuals with autism, mental retardation, and normal development. *Journal of Abnormal Psychology* **104**, 601–9.

Sobel D. M., Capps L. M. & Gopnik A. (2005) Ambiguous figure perception and theory of mind understanding in children with autistic spectrum disorders. *The British Journal of Developmental Psychology* **23**, 159–74.

Tsatsanis K. D., Noens I. L. J., Illman C. L. *et al.* (2011) Managing complexity: impact of organization and processing style on nonverbal memory in autism spectrum disorders. *Journal of Autism and Developmental Disorders* **41**, 135–47.

Van der Hallen R., Evers K., Brewaeys K. *et al.* (2015) Global processing takes time: a meta-analysis on local–global visual processing in ASD. *Psychological Bulletin* **141**, 549–73.

Vaughan C. A. (2011) Test review: E. Schopler, M. E. van Bourgondien, G. J. Wellman, & S. R. Love Childhood Autism Rating Scale (2nd ed.). Los Angeles, CA: Western Psychological Services, 2010. *Journal of Psychoeducational Assessment* **29**, 489–93.

Wechsler D. (2002) Wechsler Preschool and Primary Scale of Intelligence, 3rd Edition (WPPSI-III). In: *The Psychological Corporation*. TX, San Antonio.

Zelazo P. D., Jacques S., Burack J. *et al.* (2002) The relation between theory of mind and rule use: evidence from persons with autism-spectrum disorders. *Infant and Child Development* **11**, 171–95.

Zimmerman I. L., Steiner V. G. & Pond R. E. (2002) *Preschool Language Scale*, Fourth edn. Psychological Corporation, San Antonio, TX.

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