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Individuals with ASD seem to construct categories via processes different to typically developing individuals. We examined whether individuals with ASD engage in structural alignment of exemplars when constructing categories. We taught children with ASD and typically developing children novel nouns for either single or multiple exemplars, and then examined their extensions of the learned nouns to objects that were either a perceptual or conceptual match to the original exemplar(s). Results indicated that, unlike typically developing participants, those with ASD gained no benefit from seeing multiple exemplars of the category and, thus, did not appear to engage in structural alignment in their formation of categories. However, they demonstrated superior performance compared to typically developing children when presented with a single exemplar.

Keywords: Autism; ASD; Category learning; Structural alignment; Language learning.

Do children with Autism Spectrum Disorder benefit from structural alignment when constructing categories?

The formation of categories is an important part of developing an understanding of the world. Forming categories allows us to quickly and efficiently identify on sight what things are, what they might do, and what we may be able to use them for, amongst other things. Children show a basic understanding of categories as groups of objects that go together from early on. This understanding develops during the preschool period, with children becoming more adult-like in what they choose to base their categories on, e.g., a shared function as opposed to perceptual similarity (e.g. Clark, 1973; Nelson, 1973; Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976; Mandler & Bauer, 1988).

Gentner and colleagues have suggested that an important process utilised in category formation is structural alignment of exemplars. They suggested that when multiple exemplars of a category are presented and can therefore be compared, children mentally align the structure of the two exemplars. This alignment acts to highlight the common relational and conceptual structure between the exemplars and leads to categories based on causal or functional similarities instead of perceptual features (e.g. Gentner, 2003; Gentner & Namy, 1999; Gentner & Namy, 2006; Namy & Gentner, 2002). This suggestion is based on research that shows that when young children are asked to extend a novel noun and therefore a category to a new exemplar and when they had been exposed to only a single exemplar of the category, they often prefer shared surface-level perceptual features, such as shape, over conceptual similarity, such as shared function (e.g. Gentner, 1982; Merriman, Scott, & Marazita, 1993; Imai, et al. 1994; Smith, Jones, & Landau, 1996; Graham, Williams, & Huber, 1999). However, when multiple exemplars of a category are presented, children tend to arrive at a deeper understanding of the category, namely one based on conceptual or functional features. For instance, Gentner and Namy (1999) taught a group of typically developing 4-year-olds new words for familiar objects (e.g., a bicycle). They asked participants to extend each word to either an object that was perceptually similar to the exemplar object but from a different taxonomic category (e.g., a pair of spectacles) or to an object that was from the same category but was perceptually dissimilar (e.g., a skateboard). A second group of 4-year-olds was asked to make the same selection but were taught the words with two exemplars instead of one. The two exemplars were from the same taxonomic category, were both more perceptually similar to the perceptual choice than the taxonomic choice (e.g., a bicycle and a tricycle) and were given the same label. Participants who saw two exemplars in this study were more likely to make a taxonomic choice than participants who saw only one exemplar. This finding demonstrates how the opportunity to structurally align multiple exemplars of a category which have been labelled with the same noun can enable 4-year-olds to look past more obvious perceptual similarities of objects and notice less obvious conceptual links. This, in turn, enables the children to use deeper conceptual commonalities as a basis for the extension of category membership.

There is by now a strong case for structural alignment being a key process via which children construct categories. For instance, Gentner and Namy (1999) lists various evidence in support of structural alignment (Gentner & Markman, 1997; Gentner, Rattermann, & Forbus, 1993; Gick & Holyoak, 1983; Goldstone, Medin, & Gentner, 1991; Markman & Gentner, 1993; Markman & Gentner, 1996; Medin, Goldstone, & Gentner, 1993). But structural alignment does not necessarily happen automatically when multiple exemplars are presented. There seems to be a need to trigger the alignment process by, for instance, labelling the exemplars with the same name (Namy & Gentner, 2002; Gentner & Namy, 2006).

In contrast to typically developing children, people with Autism Spectrum Disorder (ASD) appear to form categories in a different way. Initially it had even been suggested that they may not be able to form categories (e.g., Menyuk, 1978; Fay & Schuler, 1980; Jackendoff, 1983; Schuler & Bormann, 1982, cited in Tager-Flusberg, 1985a). But, later studies suggested that they can (Tager-Flusberg, 1985a; Tager-Flusberg, 1985b; Ungerer & Sigman, 1987). While it is now generally accepted that people with ASD can and do form categories, more recent research has suggested that they may not process categories in the same way as typically developing individuals (Bott, Brock, Brockdorff, Boucher, & Lamberts, 2006; Dunn, Vaughan, Kreuzer, & Kurtzburg, 1999; Dunn & Bates, 2005; Ellawadi, Fein, & Naigles, 2017; Gastgeb, Strauss, & Minshew, 2006; Kelley et al., 2006; Naigles et al., 2013; Soulieres, Mottron, Giguere, & Larochelle, 2011; Soulieres, Mottron, Saumier, & Larochelle, 2007), or that processing categories may be more difficult for people with ASD, especially categories based on function (e.g. Shulman, Yirmiya, & Greenbaum, 1995). Note that these findings do not appear to apply only to children with ASD and language impairment, but rather to the ASD population as a whole.

Particularly striking is the suggestion that individuals with ASD may not form prototypes of categories, i.e., internal representations of best examples of categories. For instance, Klinger and Dawson (2001) suggested that individuals with ASD may rely on a rule-based approach to constructing categories instead of forming prototypes (see also Church et al., 2010; Gastgeb et al., 2012; Minshew, Meyer, & Goldstein, 2002; Plaisted, 2000). These findings are important for the current study because prototype formation requires integration of mental representations, a process also necessary for structural alignment.

Developmentally, structural alignment is a beneficial and important process for typically developing children as they progress into increasingly adult-like construction of categories. If children with ASD construct their categories in an atypical fashion and struggle with integration of mental representations, as shown in the prototype literature, they may not make use of this valuable tool, structural alignment, in their linguistic and/or cognitive development. The current study therefore aimed to investigate the ability of individuals with ASD to engage in structural alignment of multiple exemplars during construction of object categories.

It should be noted that there is heterogeneity of language development in individuals with ASD (Arunachalam & Luyster, 2016; Tager-Flusberg, 2004; Pickles, Anderson, & Lord, 2014; Wittke, Mastergeorge, Ozonoff, Rogers, & Naigles, 2017). Some individuals with ASD possess age appropriate language ability, whereas others are severely impaired in their language ability (Tager-Flusberg, 2004). In the present study, we did not focus on children who have specific difficulties with category construction or only those who have language impairment. This is because we were not necessarily aiming to find impairment in the category construction of individuals with ASD. As described above, research has demonstrated that having ASD does not prevent an individual from constructing categories, but it has also suggested that individuals with ASD may process them differently to typically developing individuals. It is this potential difference in processing that we were investigating. We were therefore interested in how people with ASD in general process categories.

To achieve the study's aim we adopted the well-established paradigm of Gentner and Namy (1999) for use with individuals with and without ASD, asking children with ASD and typically developing children to extend novel names (e.g., 'kig' for a bicycle) to one of two objects: an object from the same category as the exemplar referent but perceptually dissimilar (e.g., a skateboard) or an object perceptually similar but from a different category than the exemplar referent (e.g., a pair of spectacles). In Experiment 1 we examined whether viewing multiple exemplars of a noun category (e.g., a bicycle and a tricycle) instead of one exemplar (e.g., a bicycle) would increase the number of correct extensions to the taxonomic category match (i.e., skateboard) not only by typically developing children, as shown before (e.g., Gentner & Namy, 1999), but also by children with ASD matched on verbal and non-verbal mental age to the typically developing children.

Structural alignment occurs through the active alignment of two given exemplars of a category, which serves to highlight deeper conceptual commonalities between the two exemplars. Hearing two objects labelled with the same noun is necessary to prompt children to actively align their mental representations of the exemplars (Namy & Gentner, 2002; Gentner & Namy, 2006). This process of alignment preferentially highlights deeper conceptual commonalities, such as shared functions. When only a single exemplar is presented structural alignment of multiple exemplars is not initiated. The insight provided by structural alignment improves children's ability to use these deeper conceptual commonalities as a basis for extension of a novel noun. Therefore the ability to engage in structural alignment can be demonstrated by significantly greater extension of novel nouns to taxonomic category matches in the multiple exemplar condition, as compared to the single exemplar condition.

If children with ASD perform similarly to typically developing children and make a higher number of taxonomic extensions when viewing multiple exemplars than when viewing only a single exemplar, then this would indicate that, similar to typically developing children, they successfully structurally align the exemplars. This, in turn, would suggest that conceptual commonalities were preferentially highlighted to them as a result of the alignment process, and subsequently used as a basis for extension of category membership. In contrast, if children with ASD made a similar number of correct extensions regardless of the number of exemplars shown, then this would indicate that the presentation of multiple exemplars did not result in an alignment of the exemplars and therefore in greater attention being drawn to conceptual similarities as an essential basis for category membership.

If children with ASD do not engage in structural alignment when exposed to multiple exemplars of a category like typically developing children, then this supports the hypothesis that they do not form categories in the same way as typically developing individuals early in life. If they do exhibit structural alignment of multiple exemplars, then this suggests that they make use of the same critical early process employed by typically developing individuals in their formation of categories.

For noun extension and categorisation tasks it has been found that for young typically developing children perceptual features, such as the shape of objects, can draw attention over conceptual or functional features (e.g., Diesendruck, Markson, & Bloom, 2003, Landau, Smith, & Jones, 1998; Markson, Diesendruck, & Bloom, 2008). It has also been suggested that participants need to inhibit this perceptual bias to focus on the shape of the objects in order to extend nouns / categorise by conceptual or functional information (Smith, Jones, & Landau, 1996). Indeed, it has recently been observed that performance in a single exemplar condition of the categorisation paradigm used in the present study relies to some degree on inhibition abilities (Snape & Krott, in press). Individuals with ASD have been reported to be impaired in aspects of executive functioning, including inhibition abilities (e.g., Craig et al., 2016; Hill, 2004; O'Hearn et al., 2008; Ozonoff et al., 1994). We therefore assessed participant's inhibition abilities. For this, we assessed their behavioural performance on two tasks that index inhibition ability: Grass / Snow (Carlson & Moses, 2001) and Knock /Tap (Klenberg, Korkman, & Lahti-Nuuttila, 2001). Inhibition in both tasks involves preventing oneself from doing what comes naturally (i.e., a prepotent response) and, instead, acting in accordance with a rule. For instance, in the case of the Grass / Snow task, the experimenter says “grass” and the participant is required to point to a white piece of paper rather than a green piece, a response that goes against a natural tendency to point to the green piece of paper because grass is green. With the means of the inhibition tasks we were thus able compare the groups on inhibition ability to ensure that any overall group differences between typically developing children and children with ASD in performance on the categorisation task was not the result of differences in inhibition abilities.

We did not find any evidence of structural alignment of multiple exemplars in children with ASD in Experiment 1 and our ASD children were older than the controls in this experiment. Therefore, in Experiment 2, we tested typically developing children of the same chronological age as the children with ASD in Experiment 1, in order to directly demonstrate that children of this chronological age can and do benefit from structural alignment.

Experiment 1

Method

Participants. We tested two groups of participants. The first group consisted of participants diagnosed with Autism Spectrum Disorder (ASD). Those were recruited via a public advertising campaign and through various UK-based autism charities. The presence of an Autism Spectrum Disorder was confirmed via administration of module 3 of the Autism Diagnostic Observational Schedule (ADOS; Lord et al., 2000). The ASD group consisted of 18 participants; however 3 were removed from the sample a priori for having a verbal mental age (VMA) which was below the age necessary to pass the experimental task based on previous research (3-years; Snape & Krott, in press). This left 15 participants, with a mean chronological age of 65 months (SD = 7.2, 4 females) and a mean ADOS score of 10.6 (SD = 2.4).

The second group was a comparison group of 15 typically developing children, recruited via the University of Birmingham Infant and Child laboratory database. Both groups completed the Mullen Scales of Early learning (MSEL; Mullen, 1995). Participants from the two groups were pairwise matched on VMA (within 6 months), determined by the mean of their scores on the receptive and expressive language sub-scales of the MSEL. VMA was chosen to match the two groups as VMA had previously been found to be a better predictor of categorisation ability in children with autism than nonverbal mental age (Tager-Flusberg, 1985a). VMA matching was also used, for example, in Klinger and Dawson's (2001) investigation into prototype formation in autism. A t-test confirmed that the VMA of the two groups did not differ ($t(28) = -.057$, $p = .955$). Additionally, we calculated the mean score across the nonverbal scales of the MSEL as an index of nonverbal IQ. When comparing the two groups on this measure of nonverbal mental age (NVMA) the two groups did not differ ($t(28) = 1.653$, $p = .109$). However, this did lead to the ASD group being chronologically older than the typically developing group ($t(28) = 6.159$, $p < .001$). We can also be confident that the two group's visual perception of the experimental stimuli was very similar, as they did not differ on the visual-perception sub-scale of the MSEL ($t(28) = .612$, $p = .546$). All participants were native monolingual speakers of English. Table 1 presents a summary of chronological and mental ages for the two groups.

(Table 1 here)

Design. The categorisation experiment had a mixed experimental design. The between subjects independent variable was Participant Group (ASD vs. Typical) and the within subjects independent variable was Number of Exemplars (Single vs. Multiple). The dependant variable was number of correct extensions of nouns to taxonomic category matches.

Materials. Materials for the categorisation task were based on that of Gentner and Namy (1999). Stimuli consisted of two sets of laminated cards that displayed colour pictures of everyday objects that children would be familiar with, e.g., a balloon. There were 10 sets of 3 cards used for single exemplar trials and 10 sets of 4 cards used for multiple exemplar trials (for examples see Figure 1). Different card sets, and therefore pictures of completely different objects, were used for the single and multiple exemplar trials. This was done in order to test each participant on both the single and the multiple exemplar condition. Asking participants to respond to the same test items twice might have led to strong carry-over effects. A complete list of stimuli is included in the Appendix.

Procedure. Categorisation task. After being seated opposite the experimenter, a participant was first introduced to the experimenter's puppet, "Bear". They were told that Bear has special bear names for things, that these names are different to the names we use, and that they are going to hear some of Bear's special names for things. Participants completed 20 trials (10 single exemplar trials and 10 multiple exemplar trials).

The single exemplar trials consisted of the participant being shown a single card displaying a cartoon style picture of a familiar object, which was placed on the table in front of them; for instance a picture of a clock (see upper row of Figure 1). They also saw two more cards, placed side by side below the original card. One was a picture of an object that was perceptually similar to the original object, but not taxonomically (perceptual match); for instance a wheel. The other was a picture of an object that was from the same taxonomic category, but was perceptually dissimilar (taxonomic match); for instance a square faced wrist watch (see upper row of Figure 1). Which side the perceptual and taxonomic matches occurred on was randomised across trials. Participants then heard Bear's special name for the original object and were asked which of the other two objects the child thinks also shares that name, e.g., "Bear calls this a blik (experimenter points to the clock with Bear's hand). Which of these other two things would Bear also call a blik?" The child then pointed at one of the cards (the taxonomic match being the correct choice, e.g., the square faced watch).

(Figure 1 here)

The multiple exemplar trials differed from the single exemplar trials only in that participants were initially shown two exemplars instead of one, placed side by side. Both were cartoon style pictures of familiar objects and both from the same taxonomic category, for instance a bicycle and a tricycle (see lower row of Figure 1). Both objects were introduced with the same name, e.g., "Bear calls this a blik and this a blik", while the experimenter pointed to the relevant object with Bear's hand. The number of correct responses (i.e., taxonomic responses) were entered into the analysis.

Participants completed first the 10 single exemplar trials and then the 10 multiple exemplar trials. We did not counter-balance the order of single and multiple exemplar trials because we did not want children's performance on single exemplar trials being affected by their experience of multiple exemplars. Engaging with multiple exemplar trials before engaging with single exemplar trials could have taught them to disregard perceptual similarities as a basis for categorisation and to focus on taxonomic categories. This could have strongly affected their performance on the single exemplar trials, meaning that any benefits of structural alignment would not have been visible.

Grass / Snow (inhibition task). Adapting the paradigm by Carlson and Moses (2001), participants were told that they were going to play a game with the experimenter called the opposites game. They were then asked to tell the experimenter what colour grass is and what colour snow is. After the participant had answered, a green piece of paper and a white piece of paper were placed side by side in front of them. Participants were told that because this is the opposites game when the experimenter says grass they should point at the white piece of paper (experimenter pointed as he said this) and when the experimenter says snow they should point to the green piece of paper (the experimenter again pointed as he said this). Participants took part in two practice sessions where the experimenter said “grass, snow, snow, grass” to ensure the participants understood the task. Only when participants had successfully completed the practice sessions did they proceed onto the main trials. Participants were then told that they should point as fast as possible when they hear the experimenter say one of the names. They then received 17 test trials, with an equal number of instances where the correct response changed from the previous response and stayed the same, e.g., green then white, and green then green. Order of correct response for trials was: W, G, G, W, W, W, G, W, G, G, G, W, W, G, G, W, W (W = white paper; G = green paper). The number of correct responses was entered into the analysis.

Knock / Tap (inhibition task). Participants were told that they were going to play another opposites game with the experimenter. Adapting the paradigm by Klenberg et al. (2001), participants were asked to perform the opposite action of the experimenter. The task started with a series of two trials where the participant had to copy the experimenter’s action. For that the experimenter first knocked with their right hand and then tapped the palm of their right hand on the table and each time instructed the participant to do the same. Then followed two trials where the participant was instructed to do the opposite. For that the experimenter first tapped his hand on the table again and then knocked again. Each time he asked the participant to “Do the other one”. As the participant knocked on the table while the experimenter tapped on it (or the other way around) they were told “That’s right, when I do this, you do that.”

Next, the experimenter checked that the participant had understood what they had to do. For that he first knocked then tapped and asked each time “What do you do?” When the participants did the opposite they were praised. This demonstration was repeated if the participant was unable to perform the opposite actions to the experimenter. This was required for some participants, and provided, as the important factor was that the participant understood the game. Once participants had successfully completed the practice trials, they proceeded onto the main trials. For those the participant was told “Now the trick is you have to do it as fast as you can.” The experimenter presented 17 test trials with the following order of correct responses: K, T, T, K, K, K, T, K, T, T, T, K, K, T, T, K, K (T = tap, K = knock). There were an equal number of instances where the correct response changed from the previous response and stayed the same, e.g., knock then tap, and knock then knock. The number of correct responses was entered into the analysis.

Results

Categorisation task. Figure 2 displays the results of the categorisation task. The number of correct extensions to the taxonomic match was analysed with a mixed ANOVA with Participant Group (ASD, TD) as a between subjects factor and Number of Exemplars (Single, Multiple) as a within subjects factor. The test indicated a significant main effect of Number of Exemplars ($F(1, 28) = 13.6$, $p = .001$, partial $\eta^2 = .326$), indicating that more correct responses were produced after viewing multiple exemplars than single exemplars. There was no significant main effect of Participant Group ($F(1, 28) = 0.3$, $p = .587$, partial $\eta^2 = .011$), however the interaction between Participant Group and Number of Exemplars was significant ($F(1, 28) = 7.0$, p = .013, partial $\eta^2 = .201$). Follow-up t-tests showed that the typically developing children made correct selections significantly more often in the multiple exemplar than in the single exemplar condition (*t*(14) = -4.4, p = .001), whereas there was no significant difference between the two conditions for the ASD group (*t*(14) = -0.7, p = .472). Also, within the single exemplar condition, children in the ASD group made significantly more correct selections than typically developing children (*t*(28) = 2.2, p = .04). Within the multiple exemplar condition, there was no significant difference in performance between the two participant groups (*t*(28) = -1.0, p = .316).

(Figure 2 here)

In addition, for all conditions we conducted comparisons of the number of correct selections against chance. Typically developing children did not perform significantly above chance level in the single exemplar condition (*t*(14) = 1.4, p = .189), but they did so in the multiple exemplar condition (*t*(14) = 7.7, p < .001). In contrast, children in the ASD group performed significantly above chance level in both the single exemplar condition (*t*(14) = 4.4, p = .001) and the multiple exemplar condition (*t*(14) = 3.9, p = .002).

Participant group comparison of inhibition ability. In order to examine whether the differences in the categorisation task between the groups could potentially be explained by differences in inhibition ability, performance of the participant groups were compared for both inhibition tasks. No significant group differences were found for either of the tasks: Grass / Snow inhibition task: ASD M = 10.8, SD = 2.5; Typical M = 11.0, SD = 3.4 (*t*(28) = -0.2, p = .855); Knock / Tap inhibition task: ASD M = 10.1, SD = 2.4; Typical M = 9.8, SD = 2.0 (*t*(28) = 0.4, p = .682).

Discussion: Experiment 1

The aim of the current experiment was to determine whether children with ASD utilise structural alignment of multiple exemplars in their formation of categories. As expected based upon previous research, when typically developing children were trained using only a single exemplar, they were not able to correctly extend the novel nouns at above chance level. Without the opportunity for alignment of two named exemplars provided by the multiple exemplar condition, they were unable to systematically utilise the non-perceptual conceptual aspects of the exemplar, i.e., function, to extend the noun to the taxonomic match in an adult-like fashion. Alternatively, when these same children were taught novel nouns using two exemplars, their performance changed significantly, leading them to extend the nouns to the taxonomic match at above chance level. Thus, these children appear to have been able to utilise the multiple exemplars presented to focus on the more abstract conceptual commonalities that characterise the category, reflecting engagement in structural alignment processes.

Children with ASD, on the other hand, exhibited no significant difference in their performance between the single and multiple exemplar conditions. While their baseline taxonomic extensions in the single exemplar condition was impressively both above chance and higher than that of the typically developing children, they did not make more taxonomic extensions when presented with multiple exemplars, unlike the typically developing group. It therefore appears that children from the ASD group did not structurally align the two exemplars. Potential reasons for children with ASD’s above chance performance in the single exemplar condition are considered in the General Discussion section. As we found no group differences in performance on the inhibition tasks, we can be confident that differences in propensity to engage in structural alignment of multiple exemplars are not the result of group differences in inhibition ability.

The children in the ASD group were chronologically older than those in the typically developing group. One might argue that children of this chronological age may not benefit from the opportunity to structurally align presented multiple exemplars as they generally extend nouns on the basis of conceptual similarity and not perceptual similarity. If that was the case, it would not be surprising that children in the ASD group did not show an increase in taxonomic extensions with multiple exemplars. In order to address this potential concern, we conducted an additional experiment (Experiment 2), examining performance of typically developing children who were similar in chronological age to the ASD group in Experiment 1. If in Experiment 2, taxonomic extensions were more frequent in the multiple exemplar condition than in the single exemplar condition, then the lack of performance differences of ASD children in the conditions of Experiment 1 cannot be due to their chronological age. In addition, we utilised a between-subjects design. This was to demonstrate that the performance differences of the typically developing children between conditions in Experiment 1 was not due to a practice effect. The purpose of this experiment was therefore to experimentally demonstrate that typically developing children similar in chronological age to the ASD group can and do still benefit from structural alignment of multiple exemplars, and that the improved performance of typical children in Experiment 1 between conditions was not the result of a practice effect.

Experiment 2

Method

Participants. Participants were fifteen typically developing children in each group (single vs. multiple exemplars) for a total of thirty children with a mean age of 65.8 months (SD = 3.6, range = 60 - 71, 4 females). Participants were recruited from the same geographical region as the typically developing children in Experiment 1 and were all monolingual native English speakers. None of these participants took part in Experiment 1.

Design. The experiment had a between-subjects design. The independent variable was Number of exemplars (Single vs. Multiple) and the dependant variable was number of extensions of nouns to taxonomic category matches.

Materials. Materials used were the 10 sets of 4 cards used in the multiple exemplar condition of the categorisation task in Experiment 1. In the single exemplar condition only 3 of the cards were used, i.e., one of the exemplar cards and the perceptual match and taxonomic match cards. In the multiple exemplars condition all four cards were used.

Procedure. Apart from the fact that each participant experienced either the single exemplar condition or the multiple exemplar condition, the procedure was identical to that of Experiment 1.

Results

(Figure 3 here)

Figure 3 displays the results. The number of taxonomic (correct) selections was analysed using a between-subjects t-test, which indicated that more taxonomic responses were produced after viewing multiple exemplars than single exemplars ($t(28) = -3.4$, $p = .002$). Furthermore, performance in both the single exemplar condition ($t(14) = 2.5$, $p = .027$) and the multiple exemplar condition ($t(14) = 12.2$, $p < .001$) were found to be above chance level.

Discussion: Experiment 2

Similar to children with ASD in Experiment 1, typically developing children of the same chronological age as the ASD group made taxonomic selections at above chance levels in both the single and multiple exemplar conditions. The mean scores for the single exemplar condition are very similar for both groups (ASD group: 69%; Typical group: 64%). However, in contrast to the ASD group, who did not show significantly greater taxonomic extensions in the multiple exemplar condition (73%), typically developing children in the multiple exemplar condition showed significantly more taxonomic extensions (85%) than those in the single exemplar condition. While we cannot conduct statistical comparisons between the ASD and TD groups here because the two experiments did not have the same design (within versus between subjects design), the patterns of the means and statistical effects in the separate group and condition data demonstrate that the typically developing children in Experiment 2 made significantly more taxonomic choices in the multiple exemplar condition, relative to the single exemplar condition, while the ASD group in Experiment 1 did not. Thus, typically developing children at this chronological age still benefit from the opportunity to engage in structural alignment that the presentation of multiple exemplars offers. Therefore, the fact that children with ASD in Experiment 1 did not take advantage of multiple exemplars and therefore structural alignment opportunities during exemplar presentation cannot be explained by either their verbal mental age (Experiment 1) or their chronological age (Experiment 2). Comparing the performance level of children with ASD in Experiment 1 and age-matched typically developing children in Experiment 2 also shows that there was clear scope for children with ASD to improve their performance (i.e., no ceiling effect). In other words, of the three groups tested in this study (the ASD and typical groups in Experiment 1 plus the typical group in this experiment), only the ASD group did not exhibit significant change in performance between the single and multiple exemplar conditions.

We also observed the same pattern of change of performance in the multiple exemplar condition in Experiment 2 as in Experiment 1 despite the children in this condition in Experiment 2 not having already participated in the single exemplar condition. Therefore, the increased taxonomic choices of typically developing children in the multiple exemplar condition of Experiment 1 was not simply the result of a practice effect.

General Discussion

The present study systematically investigated whether young children with ASD make use of structural alignment of multiple exemplars like typically developing children when constructing categories. To investigate this, we assessed whether the category formation of children with ASD benefited from seeing multiple exemplars of the category. As expected from previous findings (Gentner & Namy, 1999), typically developing children showed substantially different choices in their noun and therefore category membership extensions when they were shown multiple exemplars compared to a single exemplar. This was evidenced by a significantly higher percentage of noun extensions to the taxonomic match than the perceptual match when multiple exemplars were presented in both Experiments 1 and 2. In addition, seeing multiple exemplars instead of a single exemplar allowed the younger typically developing children in Experiment 1 to make taxonomic extensions above chance level.

In contrast to typically developing children, children in the ASD group did not benefit from the presentation of multiple exemplars. They were no more likely to extend nouns (and therefore category membership) to the taxonomic match if they had seen multiple exemplars than if they had seen only one exemplar. Considering that the ASD group was chronologically older than the typically developing group in Experiment 1, and their percentage of correct responses hovered around 70% in both conditions, we checked whether there was scope for improvement in the multiple exemplar condition relative to the single exemplar condition. But the results of Experiment 2 indicate that typically developing children of this chronological age made more taxonomic extensions with multiple exemplars compared to a single exemplar. Chronological age matched children displayed a similar performance to the ASD group in the single exemplar condition, but a significantly higher number of taxonomic choices in the multiple exemplar condition, relative to their performance in the single exemplar condition.. Thus, there was indeed scope for a significant performance increase in our participants with ASD. We can also rule out the possibility that children with ASD simply remembered how they had responded in the single exemplar trial and responded in the same way during the multiple exemplar trial. This cannot be, because the stimuli used for the single exemplar condition were completely different from those in the multiple exemplar condition. ASD participants therefore never saw the same exemplars / category in the single and multiple exemplar trials. In sum, we can conclude that the children with ASD in our study did not seem to have engaged in structural alignment of multiple exemplars during category formation. Somewhat unexpected, however, they did make taxonomic extensions more often than would be expected by chance, independent of the number of exemplars that they had seen. We will return to this result below.

The use of a between-subjects design in Experiment 2 enabled us to not only show that children of the same chronological age as the ASD group can still benefit from structural alignment, but also to rule out a practice effect in the typically developing group of participants in Experiment 1. We have clearly demonstrated that children of the same chronological age as the ASD group can still benefit from structural alignment, even in a between-subjects design that strongly reduces any potential practice effects. Note that a within-subjects design would not add any information to those results. There is no reason to think that older typically developing children would only engage in structural alignment and show a change in performance in a between-subjects design. In fact, we have shown in

Experiment 1 that typically developing children will engage in structural alignment and show a performance change in a within-subjects design.

We also compared participants in the ASD group with those in the typically developing group with regards to inhibition ability and found no group differences. We originally added inhibition tests to rule out that children with ASD might not be able to pick a taxonomic match in our categorisation task because they might struggle to inhibit their focus on perceptual matches. As indicated, children with ASD unexpectedly picked the taxonomic choice more often than predicted by chance in the categorisation task. But following the original argument, we can rule out their performance being due to better inhibition ability than that of typically developing children.

Three groups of participants were tested in this study: an ASD group, a typically developing group of similar VMA and NVMA, and a typically developing group of similar chronological age. Of these groups, only the ASD group did not exhibit significantly more taxonomic noun extensions in the multiple exemplar condition relative to the single exemplar condition. Our findings therefore strongly suggest that young children with ASD may not engage in structural alignment of multiple exemplars during category formation. We now consider why this might be the case.

One potential explanation for children with ASD not engaging in structural alignment of multiple exemplars could be the long-standing proposal that they experience weak central coherence. The weak central coherence theory (Frith, 1989; Frith & Happe, 1994; Happe, 1999) suggests that individuals with ASD may have difficulty bringing information together in order to extract higher level meaning and/or context. More specifically, unlike typically developing individuals, those with ASD are suggested to be biased towards engaging in detail-focused processing, perceiving and retaining features at the expense of overall configurations and contextualised meaning (Frith, 1989, Happe, 1999; Happe & Frith, 2006). Happe (1999) has suggested that children with ASD will exhibit difficulties with tasks requiring global meaning recognition or contextualised stimulus integration, and has presented evidence from various domains to support this claim. Happe & Frith (2006) later suggested that weak central coherence may be better defined as a tendency for individuals with ASD to preference local processing over global processing than as a deficit in global processing. That is, individuals with ASD can process globally, but unless explicitly required to do so for a task they will instead preference local processing. In our experimental task not integrating stimuli could explain why children with ASD did not engage in structural alignment of multiple exemplars. In particular, they may not have carried out the mental alignment of the two exemplars necessary for structural alignment to occur, instead preferencing local processing and only focusing on each exemplar in isolation. This would also fit with findings suggesting that individuals with ASD do not necessarily utilise prototypes in their formation of categories (e.g. Klinger & Dawson, 2001; Plaisted, 2000; Church et al., 2010; Gastgeb et al., 2012), as both of these processes require the integration of mental representations to aid categorisation.

Alternatively, the alignment process might not have been initiated in children with ASD. According to Gentner (2006), words in the present paradigm are triggers for alignment. That is, when the typically developing children heard the two exemplars labeled with the same novel noun, this prompted them to align the stimuli. When children with ASD heard the two exemplars labeled with the same novel noun, this may not have prompted alignment. This would explain why we found that the ASD group performed similarly whether they were presented with a single or multiple exemplars.

While we found that children with ASD did not seem to have structurally aligned the exemplars in the multiple exemplar condition, we actually found that they chose the taxonomic match more often than chance in the single exemplar condition. Also, unlike typically developing children in Experiment 1, those with ASD performed similarly in the single and multiple exemplar conditions. Because taxonomic responses in the task are based on knowledge that categories are characterised by conceptual similarities such as shared function, this result supports the conclusion of earlier studies (Tager-Flusberg, 1985a; Tager-Flusberg, 1985b; Ungerer & Sigman, 1987) that individuals with ASD are indeed capable of learning categories. But why did children with ASD use conceptual similarity effectively in the single exemplar condition, while the VMA matched typically developing group did so only in the multiple exemplar condition? It seems that the typically developing children in Experiment 1 used conceptual similarity inconsistently, potentially being too much attracted by the shapes of the stimuli (e.g., Snape & Krott, in press). This possibility is supported by the known tendency of younger children to extend nouns on the basis of shared shape, known as the shape bias (e.g., Gentner, 1982; Landau et al., 1988; Merriman, Scott and Marazita, 1993; Samuelson & Smith, 1999; Gershkoff-Stowe & Smith, 2004). Interestingly, other lines of research have found that children with ASD do not exhibit a shape bias (Tek et al., 2008; Hartley & Allen, 2014; Potrzeba, Fein, & Naigles, 2015). Therefore, the focus of children in the ASD group probably was not pulled towards shape. This would have left them freer to utilise conceptual similarity effectively.

Critically, children with ASD not possessing a shape bias would mean that they would not necessarily need to overcome an excessive focus on shape, but it would not mean that they could not benefit from structural alignment of exemplars. Without an excessive focus on shape children's noun extensions would not automatically become adult-like. The beneficial effects of structural alignment are not just related to overcoming a focus on shape. Instead, structural alignment processes act to focus children onto shared conceptual commonalities. The presentation of multiple exemplars provides an opportunity for the individual to actively align their mental representations of the exemplars, which highlights the conceptual commonalities between the two. We suggest that it is this alignment of representations when presented with multiple exemplars and subsequent integration of the information they provide that children with ASD are not engaging in. This interpretation has potential to explain why they do not show the same improvement in performance when viewing multiple exemplars as did the chronologically similar aged typically developing children in Experiment 2, despite having a similar level of life experience with categories.

Alternatively, the superior performance of the ASD group in the single exemplar condition may reflect a more rule based approach to constructing categories as suggested by Klinger and Dawson (2001) and Minshew, Meyer, and Goldstein (2002), and could more broadly be linked to the emphasising-systemising theory of autism (e.g. Baron-Cohen, 2002; Baron-Cohen, 2006). Specifically, the superior performance in the single exemplar condition of the ASD group may be linked to the greater drive to systemise in people with ASD. Systemising involves noting regularities and rules within a system as a means of analysing the system to discern the rules that govern it. The first step of systemising is therefore a greater focus on analysing the details presented. This may have led the ASD group to engage in a greater degree of analysis when presented with only a single exemplar, than did typically developing children. They therefore did not need the additional exemplar and opportunity to engage in structural alignment of exemplars in order to perform above chance level. A greater drive to systemise may buffer against the attentional draw of more obvious perceptual similarities, yet reflect differential processes underlying the development of categorisation in children with ASD.

Therefore, while we have found that children with ASD did not make use of a process used by typically developing children, we did find that they were more successful than typically developing children in situations where this process could not be utilised. It is important to note that our aim with this study was not to show evidence of impairment in the ASD population. We rather set out to investigate whether individuals with ASD utilise structural alignment of multiple exemplars in their construction of categories, with the aim of adding to the discussion of whether individuals with ASD construct categories in the same way as typically developing individuals. Our findings therefore add to the literature suggesting that individuals with ASD may process or construct categories differently (e.g. Klinger & Dawson, 2001; Minshew, Meyer, & Goldstein, 2002; Ellawadi, Fein, & Naigles, 2017). It is possible that the reliance on alternative processes could lead to some qualitative differences in the categories of individuals with ASD. More broadly, our findings also provide further support for a pattern of relatively unique strengths and weaknesses in the language development of individuals with ASD (see Naigles & Tek, 2017 for a review).

Our study aimed to focus on category construction in the ASD population as a whole and not at a particular sub-section of the ASD population. Our sample is too small to investigate any differences in category formation in children with, for instance, stronger or weaker verbal abilities. This might be a constructive avenue for future research. The outcome of this study also has potential to inform strategies for helping children with ASD who are struggling with category learning. If children with ASD are constructing categories via different processes to typically developing children, then it may be that intervention strategies that tap processes that typically developing children use to form categories, but children with

ASD do not, are less appropriate for those with ASD. Furthermore, application of procedures to assess category learning and other related skills in vivo may help to inform whether and which individuals with ASD exhibit atypical category processes. As such, interventions might be tailored to address the strengths and weaknesses of each individual with ASD, with increased data-based understanding to suggest that atypical category learning is associated with ASD.

In summary, we have systematically investigated whether children with ASD engage in structural alignment in their formation of categories. In contrast to typically developing children, we observed that children with ASD did not make use of structural alignment of multiple exemplars. This finding is consistent with previous suggestions that, while individuals with ASD are capable of forming categories, they likely do so via different processes to those employed by typically developing individuals. By utilising a paradigm developed and adapted for the testing of young children, and by accounting for both verbal, nonverbal and chronological age in our samples, the current findings particularly further our understanding of a relatively early developmental stage of verbal category learning in ASD.

Ethical approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent: Informed consent was obtained from all individual participants included in the study.

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Appendix

Pictures used in single exemplar condition of structural alignment task

Set	Exemplar	Perceptual match	Taxonomic match
1	Hammer	Cross	Saw
2	Guitar	Squash	Piano
3	Purse	Rock	Wallet
4	Sock	Deflated balloon	T shirt
5	Training shoe	Iron	High heeled boot
6	Surf board	Ironing board	Boat
7	Mobile phone	Bar of soap	House phone
8	Oak tree	Candyfloss	Palm tree
9	Triangular sandwich	Pyramid	Beef burger
10	Clock	Wheel	Square faced watch

Pictures used in multiple exemplar condition of structural alignment task and control experiment

Set	Exemplar 1	Exemplar 2	Perceptual match	Taxonomic match
1	Apple	Pear	Balloon	Banana
2	Plate	Bowl	Cookie	Casserole dish
3	Drum	Tambourine	Hat box	Flute
4	Carrot	Corn	Rocket	Turnip
5	Ice cream	Lollipop	Spinning top	Chocolate bar
6	Baseball cap	Bowler hat	Igloo	Sombrero
7	Bicycle	Tricycle	Glasses	Skateboard
8	Caterpillar	Snake	Rope	Turtle
9	Baseball bat	Golf club	Pencil	Tennis racket
10	Baseball	Beach ball	Orange	Football

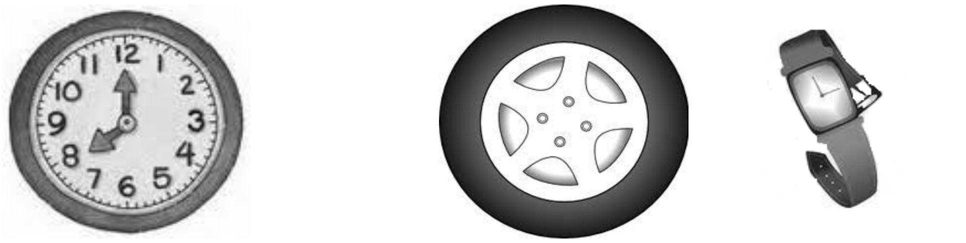
Figure Captions

Figure 1. Example stimuli for categorisation task. The first row displays a single exemplar trial. The second row displays a multiple exemplar trial. Noun extensions can be made to either the perceptual match, which is more perceptually similar to the exemplar(s), or to the taxonomic match, which is from the same taxonomic category as the exemplar(s).

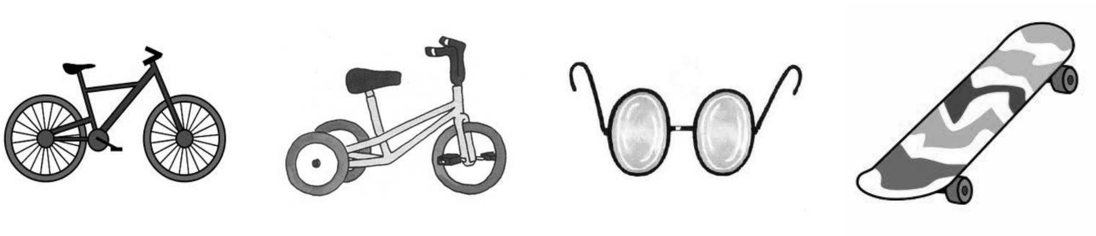
Figure 2. The effect of number of exemplars on ability to extend nouns to taxonomic match in the two participant groups (50% line marks chance level) in Experiment 1. Error bars represent standard errors of the mean. The ASD group did not show a significant difference in correct responding between conditions, whereas the typical group did. Thus, the ASD group did not benefit from the opportunity to engage in structural alignment that the presentation of multiple exemplars offered.

Figure 3. Experiment 2: The effect of number of exemplars on ability to extend nouns to taxonomic match (50% line marks chance level). Error bars represent standard error. Typically developing children correctly extended nouns to the taxonomic match significantly more often in the multiple exemplar condition than in the single exemplar condition.

Figure 1 top



Exemplar Perceptual match Taxonomic match



Exemplar 1 Exemplar 2 Perceptual match Taxonomic match

Figure 2 top

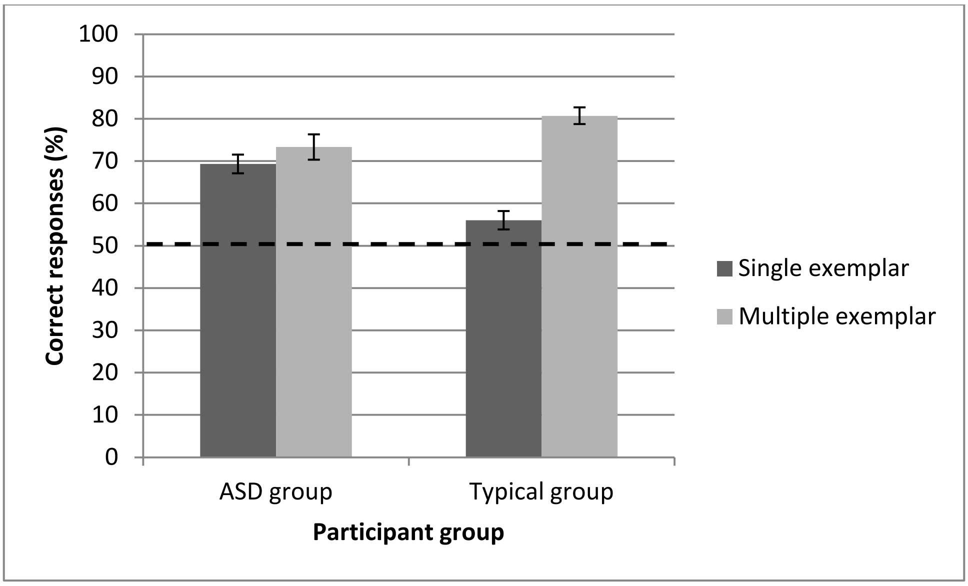

100
90
80
70
60
50
40
30
20
10
0
Correct responses (%)
ASD group
Typical group
Participant group
Single exemplar
Multiple exemplar

Figure 3 top

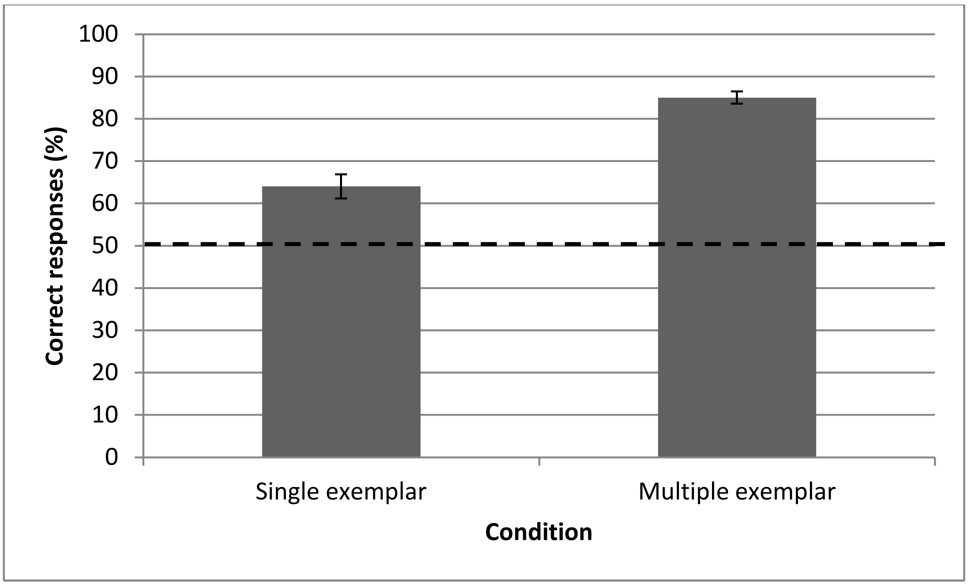

100
90
80
70
60
50
40
30
20
10
0
Correct responses (%)
Single exemplar
Multiple exemplar
Condition

Table 1: Summary of chronological and mental ages for Experiment 1 (mean / standard deviation / range)

Group	Chronological Age (months)	VMA (months)	NVMA (months)
ASD	64.9 / 7.2 / 54 - 79	52.0 / 8.8 / 38 - 68	55.3 / 6.6 / 45 - 65.5
Typical	50.1 / 5.9 / 39 - 60	52.2 / 7.1 / 38.5 - 62.5	51.1 / 7.1 / 31.5 - 62.5