Biological motion and the animate–inanimate distinction in children with high-functioning Autism Spectrum Disorder

Article *in* Research in Autism Spectrum Disorders · May 2016

DOI: 10.1016/j.rasd.2016.01.005

Kristyn Wright
Concordia University Montreal

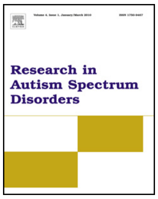
Diane Poulin-Dubois
Concordia University Montreal

Research in Autism Spectrum Disorders 25 (2016) 1–11

Contents lists available at ScienceDirect

Research in Autism Spectrum Disorders

journal homepage: http://ees.elsevier.com/RASD/default.asp



Research in Autism Spectrum Disorders

Biological motion and the animate–inanimate distinction in children with high-functioning Autism Spectrum Disorder

Kristyn Wright[a,*], Elizabeth Kelley[b], Diane Poulin-Dubois[a]

[a] *Department of Psychology, Concordia University, Montréal, Canada*
[b] *Department of Psychology, Queen's University, Kingston, Canada*

ARTICLE INFO

Article history:
Received 12 June 2015
Received in revised form 13 January 2016
Accepted 14 January 2016
Available online xxx

Keywords:
Autism Spectrum Disorder
Biological motion
Social orienting
Animate–inanimate distinction

ABSTRACT

The current study examined whether children with high-functioning Autism Spectrum Disorder (HF-ASD) preferentially attend to point-light displays of biological, compared to mechanical motion. We hypothesized that children's attentional patterns toward the motion of living things would be reduced compared to typically developing (TD) children. Children also completed two categorization tasks measuring the animate–inanimate distinction. Children with HF-ASD were matched with TD children ($n = 18$ per group) on age, gender, and verbal ability. Overall, children with HF-ASD attended to biological and non-biological motion equally, whereas TD children demonstrated a preference for inanimate motion. Children with HF-ASD were also unimpaired in the formation of animate and inanimate concepts. Among children with HF-ASD, a link between attention to motion and categorization ability was observed, but only for inanimate objects. TD and HF-ASD groups differed in that visual exploration of the motion videos (e.g., saccades) was related to animate–inanimate categorization only among children with HF-ASD. These results are discussed as a low-level test of the social attention/orienting hypothesis.

1. Introduction

Investigations of children's preference for social, compared to non-social, aspects of the environment have gained momentum, particularly as these investigations relate to the social motivation theory of ASD. Research has shown that one of the earliest behavioral markers associated with ASD is abnormal attentional preference for non-social aspects of the environment (Dawson, Meltzoff, Osterling, Rinaldi, & Brown, 1998; Swettenham et al., 1998; Webb et al., 2010). Specifically, this research has shown that infants with ASD as young as 20 months demonstrate social orienting deficits, whereby they are less likely to orient their gaze toward people, more likely to shift their gaze from object to object (Swettenham et al., 1998), show a lack of preference for social compared to geometric scenes (Pierce, Conant, Hazin, Stoner, & Desmond, 2011), and spend less time attending to faces during dynamic social interactions (Shic, Bradshaw, Klin, Scassellati, & Chawarska, 2011).

In addition to deficits in orienting toward realistic social stimuli, evidence for an early emerging disruption in attention to the biological motion of animate beings has also been consistently reported in toddlers with ASD (Klin & Jones, 2008). Specifically, whereas even TD newborns orient toward biological motion and prefer this motion compared to random or scrambled the motion (Bardi, Regolin, & Simion, 2010; Simion et al., 2008), toddlers and young children with ASD pay less attention to biological motion compared to non-social motion (Annaz, Campbell, Coleman, Milne, & Swettenham, 2012;

---

[*] Corresponding author at: Department of Psychology, Concordia University, Psychology Building PY-276, Canada. Fax: +1 514 848 2815.
E-mail address: kr_wrigh@live.concordia.ca (K. Wright).

http://dx.doi.org/10.1016/j.rasd.2016.01.005
1750-9467/© 2016 Published by Elsevier Ltd.

Falck-Ytter et al., 2013; Klin, Lin, Gorrindo, Ramsay, & Jones, 2009). This disruption in visual preference for biological motion has been proposed as a hallmark of ASD (for a review see Kaiser & Pelphrey, 2012; Pavlova, 2011, 2013).

Another body of research challenges the notion that deficits in biological motion perception and social orienting are a universal feature of ASD, and instead supports the notion that these abilities are either compensated for, or have had the opportunity to develop, by adolescence or adulthood (Cleary, Looney, Brady, & Fitzgerald, 2013; Freitag et al., 2008; Hubert et al., 2007; Moore, Hobson, & Lee, 1997; Murphy, Brady, Fitzgerald, & Troje, 2009; Rutherford & Troje, 2012; Saygin, Cook, & Blakemore, 2010). Recently, Flanagan, Brodeur, and Burack (2015) expanded on these developmental findings by showing that that pre-adolescent children with ASD (CA = 10 years, NVMA = 8.5 years) were unimpaired in visually orienting toward social, compared to non-social, stimuli. Thus, one of the main goals of the present study was to test whether younger children with high-functioning ASD (HF-ASD) orient toward biological motion and/or show an attentional preference for biological motion when contrasted with both mechanical and random motion.

It is also possible that the observed deficits in biological motion perception are part of a broader pattern of deficits in animacy perception, which affect the perception of a host of animate motion cues. Previous research has identified deficits in the use of other animate motion cues (e.g., contingency, acceleration, deceleration, self-starting) when children with ASD make animacy attributions (Klin & Jones, 2006; Johnson & Rakison, 2006; Rutherford, Pennington, & Rogers, 2006). Additionally, although children with ASD have been shown to possess knowledge of the motion patterns of animates (e.g., having legs is correlated with walking), they were found to lack knowledge of the broader significance of possessing legs in relation to the animate concept (e.g., things with legs are living) (Johnson & Rakison, 2006). Children with HF-ASD have also been found to be more likely to describe the biological motion of a stimulus using inanimate descriptors (e.g., rectangles), while TD children, in contrast, used animate descriptors (e.g., caterpillars) (Congiu, Schlottmann, & Ray, 2010). In sum, research addressing animacy perception in children with ASD largely suggests deficits in the formation of an animacy concept based on motion cues. However, the ability to form animate and inanimate categories among children with ASD has yet to be investigated. Thus, a secondary goal of this research was to test whether children with HF-ASD were impaired on cognitive measures of the animacy concept, namely the ability to form explicit animate and inanimate categories.

In typical development, research investigating the development of an implicit form of animacy concept among infants supports the notion that attention to motion plays a key role in cognitive development (Gelman & Spelke, 1981). Theorists have identified motion as an organizational mechanism that directs infants' attention to socially relevant information, such as whether an entity is animate or inanimate, is goal directed, or is intentional (Gelman & Opfer, 2002; Mandler, 1992; Opfer & Gelman, 2010; Rakison & Poulin-Dubois, 2001). More recently, infants' ability to differentiate implicit animate and inanimate concepts was shown to be facilitated by animate, biological motion cues (Poulin-Dubois, Crivello, & Wright, 2015). However, the question of whether motion continues to be important to the development of children's explicit animate versus inanimate (A–I) categories remains to be explored. The development of A–I categories in TD children has primarily been investigated using tasks requiring categorical inferences based on biological properties (Gottfried & Gelman, 2005; Inagaki & Hatano, 1996; Jipson & Gelman, 2007; Margett & Witherington, 2011). This body of research has shown that knowledge of biological properties such as the ability to eat, grow, think, and feel, as well as the internal structure of animates, emerges between 4 and 6 years of age. In one of the few studies to examine the ability to form animate and inanimate taxonomic categories, Wright, Poulin-Dubois and Kelley (2015) showed that by 5 years of age A–I categorization was above chance, but was not as well developed as adults'.

Whether children with ASD form animate–inanimate level categories similar to their TD peers has not been thoroughly investigated. However, there is reason to hypothesize that the A–I categories would be particularly challenging for children with ASD given that such global categories possess few common observable features. Therefore, unlike lower level categories such as dogs, or vehicles, A–I categories cannot be easily formed using a rule-based strategy. It has been suggested that children with ASD rely on a rule-based approach to categorization (Klinger & Dawson, 2001). Furthermore, the detail-focused cognitive style characteristic of ASD (Happé & Frith, 2006) may make it difficult for children to identify broader categories such as animates and inanimates.

The current body of research has yielded inconsistent findings concerning whether deficits in categorization at less inclusive levels are present in ASD (e.g., Gastgeb, Strauss, & Minshew, 2006; Klinger & Dawson, 2001; Molesworth, Bowler, & Hampton, 2005; Soulières, Mottron, Giguere, & Larochelle, 2011). For instance, Gastgeb et al. (2006) showed that while 10-year-old children with high-functioning ASD were unimpaired in categorizing superordinate (e.g., animal) and basic (e.g., dog) level categories, they responded more slowly when exemplars deviated from the most typical instances of a particular category. Other research using an object sorting procedure, however, showed that mental age matched individuals with ASD (mental age of 9 years) were impaired in categorizing representational objects from basic and superordinate level categories compared to individuals with intellectual disability and TD children (Shulman, Yirmiya, & Greenbaum, 1995). In the extant literature, there has yet to be an investigation of whether children with ASD form the A–I distinction by attending to the same information as TD children, or do so on the same developmental timetable. This area of inquiry is particularly relevant given the evidence that children with ASD attend to inanimate as opposed to animate aspects of their environment. Thus, it may be expected that children who attend to inanimate aspects of the environment (i.e., inanimate biological motion) may be better able to categorize inanimate, as opposed to animate stimuli, while the converse would be expected to be true for children who show an attentional preference toward animates.

The goals of the current investigation were thus threefold. The first goal was to test the assumption that deficits in attention to animate, biological motion stimuli are present in young school-aged children with HF-ASD. Secondly, this research aimed to investigate whether children with HF-ASD are specifically impaired in forming animate, as opposed to inanimate, categories. A final exploratory aim of this research was to investigate whether different aspects of children's attention to biological motion (e.g., visual orienting, preference, visual exploration) relate to the ability to categorize animates, compared to inanimates, among TD children and children with HF-ASD.

To measure children's attention to biological, compared to non-biological motion, a preferential looking task was developed using point-light displays of animate (e.g., human, cat) and inanimate (e.g., bicycle, truck, randomly moving dots) stimuli, which were presented as split-screen videos. In contrast to previous research using the preferential looking paradigm whereby the same stimuli are presented repeatedly across trials (Annaz, Campbell, Coleman, Milne, & Swettenham, 2012; Simion et al., 2008), we presented an array of novel biological and non-biological motion contrasts to avoid habituation and increase ecological validity. Presenting biological motion stimuli as a preferential looking task allows for the measurement of a number of variables related to children's attention, including: visual orienting toward biological motion (e.g., first fixation), relative preference for biological motion (e.g., total looking duration), as well as active visual exploration or comparison of stimuli (e.g., number of saccades).

With respect to the first aim of the study, in line with previous research (Falck-Ytter, Rehnberg, & Bölte, 2013; Klin & Jones, 2008), we expected that children with HF-ASD would show a diminished orienting response to biological motion and would pay less attention to this motion across the total trial duration compared to TD children. Our second aim was to test whether children with HF-ASD form animate and inanimate taxonomic categories as proficiently as mental age matched TD peers. Although previous research has not addressed this question directly, investigations of animacy perception in ASD generally point to deficits in animacy perception (Congiu, Schlottmann, & Ray, 2010; Johnson & Rakison, 2006). Thus, we hypothesized that children with HF-ASD would be impaired in their ability to form animate categories. Furthermore, based on the documented attentional bias toward inanimate aspects of the environment (Dawson et al., 1998; Shic, Bradshaw, Klin, Scassellati, & Chawarska, 2011; Swettenham et al., 1998) we predicted that children with HF-ASD would be better able to categorize inanimates compared to mental age matched peers.

Our final exploratory aim was to investigate whether different aspects of attention to biological motion concurrently relate to children's ability to categorize animates and inanimates. Previous research has shown that simple exposure to biological motion primes A–I categorization in TD infants (Poulin-Dubois, Crivello, & Wright, 2015). However, in childhood more active processing of motion information may be expected to drive category learning. We reasoned that the active process of visually comparing animate and inanimate motion (i.e., the number of saccades between animate and inanimate motion) would be positively associated with the ability to form A–I categories across both HF-ASD and TD groups. Based on the social/non-social attention hypothesis, we predicted that children who spent more time attending to animate, biological motion would be better at forming animate categories, whereas children who spent more time attending to inanimate motion would be better able to categorize inanimates.

2. Method

2.1. Participants

The HF-ASD group consisted of 18 children (15 males) with a diagnosis on the autism spectrum, while the TD control group consisted of 18 children (15 males). Two additional participants were tested but not included ($n = 1$ TD male; $n = 1$ HF-ASD female) as they demonstrated a clear bias toward looking at one side of the screen across all six trials (>80% of total looking time) regardless of which category of stimuli were presented.

Participants in the HF-ASD group were recruited from a University database, a hospital with specialized autism diagnostic services, as well as referrals from specialized centers treating children with ASD. Participants were not included if their full scale IQ on a standardized IQ test was below 70. All participants in the HF-ASD group had previously received a clinical diagnosis on the autism spectrum by satisfying the Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition (DSM-IV-TR) criteria, as well as the diagnostic thresholds on the Autism Diagnostic Observation Schedule (ADOS; Lord et al., 2000). The Social Communication Questionnaire (Rutter et al., 2003) was administered to provide additional information about current symptoms of ASD.

Participants from the TD comparison group were recruited from a University database. TD participants had no other neurological or developmental disorders (e.g., epilepsy, language delay) and did not have any known first-degree relative

Table 1
Participant characteristics for HF-ASD and TD groups.

	HF-ASD *M* (SD)	TD *M* (SD)	*t*	*p*
Chronological age	6.61 (1.29) range 4.67– 9.16	6.41 (1.75) range 4.17–10.08	.40	.70
Verbal IQ	102 (19.03)	105.22 (11.44)	.62	.54
Non-verbal IQ	102.82 (16.07)	106.61 (9.88)	.85	.40
Verbal mental age	6.75 (2.06)	7.11 (2.35)	.48	.63

with an ASD. All participants completed the Differential Abilities Scale, Second Edition (DAS-II; Elliott, 2007). HF-ASD and TD groups were matched on gender, chronological age, and verbal IQ. Table 1 shows the mean chronological age, verbal and nonverbal IQ scores for each group.

2.2. Materials and procedure

Children completed the tasks in a fixed order, wherein the matching-to-sample task was administered first, the object sorting task second, the biological motion task third, and the test of cognitive ability administered last. Tasks were administered in this order to obtain reaction times on the matching-to-sample task that would not be affected by fatigue or practice. The biological motion preference task was administered after the categorization tasks to ensure that exposure to biological motion stimuli did not prime children's ability to differentiate animate–inanimate categories, as has been previously shown to occur in TD children (Poulin-Dubois, Crivello, & Wright, 2015).

2.2.1. Matching-to-sample categorization task

The matching-to-sample task is a forced-choice test of categorical association, whereby children were asked to decide which of two images were the "*same kind of thing*" as a centrally located sample image. Children were presented with one taxonomic match and one unrelated match, in order to provide an assessment of whether children possess the given category (e.g., dog [sample] presented with a human [taxonomic match] and a Table [unrelated match]). In the current study children were tested not only on their ability to categorize at the animate–inanimate level, but trials assessing less inclusive concepts (i.e., basic and superordinate) were interspersed to assess a wider range of categorization abilities. These trials were used to maintain children's motivation toward the task as they provided varying levels of difficulty. Animate–inanimate level trials assessed children's ability to form concepts of animates (including both people and animals) as well as inanimates (including both furniture and vehicles).

Five training trials were presented, followed by 24 test trials; 8 trials for each categorization level. All images were selected to be the most typical exemplars of each category based on ratings described in previous research (Rosch & Mervis, 1975; Uyeda & Mandler, 1980). Children provided their responses by touching a 30-inch touch-screen computer, which recorded both accuracy and reaction time. Previous research suggests that reaction time may be a more sensitive indicator of differences in cognitive processing in children with ASD, particularly when no group differences in accuracy are found (Gastgeb, Strauss, & Minshew, 2006; Soulières et al., 2011). Training consisted of five subordinate level trials. Feedback was provided in the form of a green check-mark appearing over correct responses and a red "x" appearing over incorrect responses. The experimenter also provided an explanation for the correct response if children responded incorrectly.

During the test phase, children were not given feedback on the accuracy of their responses but were simply encouraged to keep going. The presentation of test trials was fixed and pseudo-randomized so that trials of the same categorization level never occurred on more than two consecutive trials. An equal number of test trials contained animate versus inanimate sample images. The correct response option was also counterbalanced to occur equally often on each side, and did not occur on the same side for more than two consecutive trials. At the animate–inanimate level, trials were constructed to ensure that children's ability to categorize taxonomically was measured, as opposed to a preference for thematic relatedness. That is, sample images were always those of animals, rather than people, to prevent children from matching people with thematically related objects, such as vehicle or furniture. Presentation of trials and recording of responses was programmed using E-Prime software (Schneider, Eschman, & Zuccolotto, 2002). Percent correct was our measure of accuracy and only the animate–inanimate level was analyzed for the purposes of the current study. Similarly, children's reaction time (RT) on animate–inanimate level trials were recorded as an average across trials.

2.2.1.1. Content validation. A group of 21 adults completed the matching-to-sample task to assess how well each trial measures taxonomic associations. We used the criteria of 85% correct to define trials that measure the intended concept. One animate–inanimate level trial was identified as problematic as only 10% of adults responded correctly. This trial was therefore removed from subsequent analyses.

2.2.2. Object sorting categorization task

In the current experiment, we adapted the object sorting task (Markman, Cox, & Machida, 1981; Starkey, 1981) to provide spatial structure using transparent plastic bowls. Children were provided with one category exemplar in each bowl, and were subsequently given 6 figurines (of people, animals, furniture, and vehicles) to be sorted. Similar to the matching-to-sample task, typical exemplars of each category were selected.

Children first participated in a brief training phase during which the experimenter demonstrated how to complete the task using simple object anchors in the bowls (e.g., sorting ice-cream cones vs. grapes). The experimenter then took a third object and demonstrated how to categorize it into the correct bowl. Children were given the remaining objects to categorize and corrective feedback was provided if children made sorting errors.

Two test trials were administered to assess animate–inanimate level categorization. As in the matching-to-sample procedure, additional basic and superordinate level trials were administered to provide an assessment of children's categorization skills at varying levels of difficulty. A total of six test trials were administered, with the presentation order of each level counterbalanced. On test trials, category anchors were provided in each bowl and children were subsequently handed objects to categorize, one by one. Children were instructed to place each object in the bowl with "*the same kind of thing.*" Unlike the matching-to-sample procedures, children were free to form either taxonomic (e.g., people and animals) or thematic (e.g., people and furniture/vehicles) categories. Each trial consisted of six objects to be sorted, three objects from each category. Following each sorting trial children were asked, "*What makes these the same kind of thing?*" to assess explicit knowledge of these categories.

At the animate–inanimate level, two category anchors were drawn from four possible pairings: person-vehicle, person-furniture, animal-vehicle, and animal-furniture. Each child completed one trial with a person as the anchor and one trial with an animal as the anchor. At the A–I level, an additional object (matching the animate anchor) was included, but not scored, to ensure the A–I category contained at least two people and three animals, or vice versa.

The object sorting task was coded for both accuracy of taxonomic sorting and verbal explanation why each group of toys was "*the same kind of thing*." The coding scheme for taxonomic accuracy was adapted based on previous object classification studies (Sugarman, 1983). A score of two was given if the child sorted both categories without error. A score of one was given if the child made one sorting error. A zero score was given if the child made two or more sorting errors. Children who sorted objects according to a thematic, rather than taxonomic, association received a score of zero. For each categorization level a total possible score of four was computed; however, only the animate–inanimate level was analyzed for the purpose of this study. In order to compare animate–inanimate categorization performance across matching-to-sample and object sorting tasks, scores ranging from zero to four were converted a scale ranging from 0 to 100% correct.

Children's verbal responses were coded based on a scoring system described in previous research (Kagan, Moss, & Sigel, 1963; Sigel, Anderson, & Shapiro, 1966). Children's verbal responses were coded as *taxonomic, thematic, perceptual*, or *no response*. A *taxonomic* response was any reference to the kind of thing the objects are (e.g., living things, non-living). A *thematic* response was any response that described a thematic association among objects (e.g., people and their pets, things people use, things in the house). A *perceptual* response was any response that focused on observable features (e.g., all have eyes, wheels, move on their own). Multiple responses for the association between the same set of objects were possible and were coded according to the above criteria.

A second experimenter coded 27% of the sample and inter-rater reliability was calculated as Kappa = .97 (with 99% agreement) for children's sorting accuracy score. Inter-rater agreement for the classification of children's verbal responses for each category was calculated as Kappa = .92 (with 93% agreement).

2.2.3. Biological motion task

Each trial was composed of two videos of point-light displays placed on either side of the screen, one animate and one inanimate. During the presentation of the motion trials children were instructed to watch the screen, but did not receive instruction about what, specifically, they should pay attention to. This task provided a comparison of children's relative visual interest in biological versus inanimate motion. The directional motion (e.g., leftward or rightward), and placement of the animate stimuli (e.g., left or right side) was counterbalanced across all trials. Each individual point-light video contained 11 dots, which were placed on the key parts of the human and cat (e.g., head, neck, shoulders, elbows, pelvis, hips, legs) and major areas of the truck (e.g., wheels [three per wheel], front bumper, back bumper, roof) and bicycle's frame (e.g., wheels [three per wheel], seat, frame, handle bars). The point-light video of a human was provided by Troje (2002), while the cat, truck and bicycle stimuli were adapted from Arterberry and Bornstein (2001). The human point-light display was shown in front view, while all other stimuli were shown at a visual angle of 60° to allow all four limbs or two wheels to be visible. Dots did not possess animate motion cues such as the ability to change speed, direction, or move contingently with any other dot. In the random motion video, directionality was controlled by having an equal number of dots move left, right, up and down.

Children were seated in front of a 30-in. computer monitor equipped with a centrally-located camera located above the screen. Children's visual fixations to either the left or right side of the screen during the presentation of split-screen stimuli were recorded using the camera and coded offline. Stimuli were programmed and presented using E-Prime software (Schneider et al., 2002). Six different video pairings were shown: cat-bicycle, cat-truck, cat-random, human-bicycle, human-truck, and human-random. Trials were presented in a pseudo-randomized order so that the animate motion stimuli never appeared on the same side for more than two consecutive trials and appeared on each side for half the trials.

To begin each trial, a centrally located fixation cross accompanied by the sound of a bell appeared on screen to ensure that children's eye gaze at the start of each trial was equidistant between the biological and inanimate motion stimuli. Valid trials were considered those in which the child had looked at each of the two stimuli at least once within each 6 s trial.

Children's attention to either biological or non-biological motion was coded frame-by-frame using Interact 13.0 software (Mangold International, 2014). The coder was blind to the location of the biological or non-biological motion stimuli. Three dependent variables were coded: (1) orienting response (i.e., first saccade away from the central fixation cross), (2) attention to biological motion (i.e., proportion of time spent looking at biological motion out of the total time spent on screen), and (3) visual exploration (i.e., the number of saccades between animate and inanimate motion).

A second blind experimenter, coded 50% of the sample for reliability. Across all six trials, Pearson product-moment correlations comparing values for total looking time between coders averaged $r = .90$ (range = .82–.98). Coder agreement for the direction of the orienting response was 93%, which controlling for chance agreement produced a Kappa of .86. Coder agreement for the number of saccades on each trial was computed as a two-way mixed interclass correlation with two raters, which produced an ICC of .86.

3. Results

3.1. Biological motion task

A two-tailed independent samples *t*-test revealed no group differences in orienting toward biological motion between HF-ASD ($M = 60\%$ of trials, $SD = 23\%$) and TD groups ($M = 61\%$ of trials, $SD = 17\%$), $t(34) = .06$, $p = .96$, $d = .02$. Chance analyses showed that whereas the TD group oriented toward biological motion at a rate above chance (i.e., 50%), $t(17) = 2.67$, $p = .02$, the orienting response in the HF-ASD group only showed a tendency to be significantly different from chance, $t(17) = 1.88$, $p = .08$.

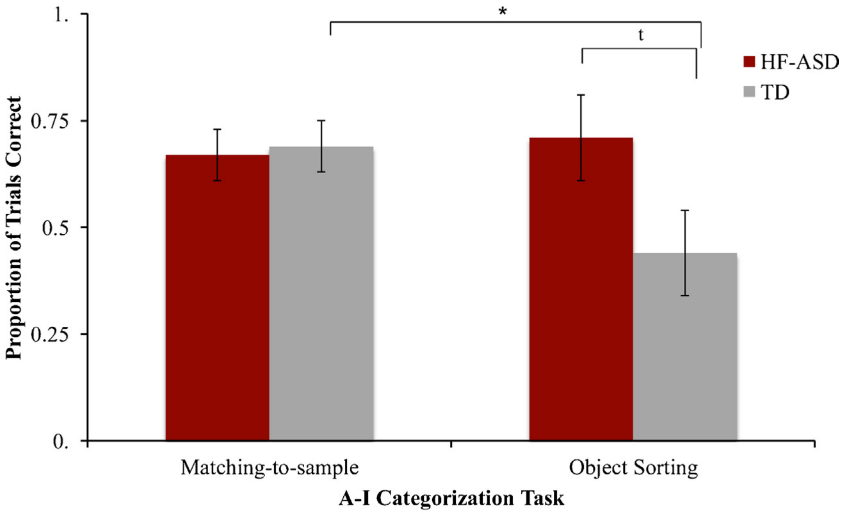
A two-tailed independent samples *t*-test revealed group differences in proportion of total looking time spent on biological motion between HF-ASD ($M = .51$, $SD = .10$) and TD groups ($M = .43$, $SD = .10$), $t(34) = 2.55$, $p = .02$, $d = .85$. Chance analyses revealed that the HF-ASD group did not demonstrate preferential attention to either the biological motion or inanimate motion, $M = .51$, $t(17) = .63$, $p = .54$. In contrast, the TD group demonstrated a below-chance looking durations, $M = .43$, $t(17) = -3.50$, $p < .01$, indicating greater visual attention toward the inanimate motion.

Visual exploration during each trial was measured as the number of saccades children made between the animate and the inanimate motion displays during each 6 sec trial. Preliminary analyses revealed that the number of saccades did not significantly differ by trial type. Thus, we analyzed the average number of saccades across all six trials. A two-tailed independent samples *t*-test revealed no group differences in the amount of visual exploration HF-ASD ($M = 3.38$, $SD = .84$) and TD ($M = 3.40$, $SD = .64$) children made, $t(34) = -.01$, $p = .92$, $d = .03$.

A group of adults ($n = 11$) were also tested on the biological motion task to examine whether the performance of the TD children could be considered developmentally appropriate. Consistent with the performance of TD children, adults did not demonstrate visual preference for animate motion ($M = .54$, $SD = .09$) at a level significantly greater than chance, $t(10) = 1.39$, $p = .20$. Adults, like the group of TD children, oriented toward biological motion at a rate significantly greater than expected by chance, $M = 71\%$ of trials ($SD = 23\%$), $t(10) = 3.07$, $p = .01$. Adults, however, made more saccades between biological and non-biological motion stimuli ($M = 4.56$; $SD = 1.19$) compared to TD children ($M = 3.40$, $SD = .64$) and children with HF-ASD ($M = 3.38$, $SD = .84$), $F(2, 44) = 7.71$, $p < .01$, partial $\eta^2 = .26$.

3.2. Animate and inanimate categorization

To examine group differences in performance on the A–I categorization tasks, a 2 (Group) × 2 (Task) ANOVA was computed. This analysis revealed no main effect for group, $F(1, 34) = 1.73$, $p = .20$, partial $\eta^2 = .05$, indicating HF-ASD children performed as well as TD children on animate–inanimate categorization, *M* HF-ASD = 69% correct ($SD = 31\%$); *M* TD = 57% ($SD = 36\%$). No main effect for Task was found, $F(1,34) = 2.21$, $p = .15$, partial $\eta^2 = .06$. Finally, a significant Group × Task interaction was found, $F(1,34) = 4.03$, $p = .05$, partial $\eta^2 = .11$, whereby follow-up pairwise comparisons (with Bonferroni correction) revealed that on the object sorting task children with HF-ASD, $M = 71\%$ ($SD = 39\%$) tended to perform better than TD children, $M = 44\%$ ($SD = 48\%$), $p = .08$. Within the HF-ASD group, children performed similarly well on the matching-to-sample, $M = 67\%$ ($SD = 24\%$) and object sorting task, $M = 71\%$ ($SD = 39\%$), indicating that across both tasks a taxonomic



* denotes $p < .05$, *t* denotes $p < .10$

Fig. 1. Categorization performance as a function of group and task.

categorization strategy was adopted. Among TD children, taxonomic categorization was demonstrated on the matching-to-sample task, $M = 69\%$ ($SD = 24\%$), but not maintained when given the opportunity to switch to a thematic sorting strategy in the object sorting task, $M = 44\%$ ($SD = 48\%$), $p = .02$ (Fig. 1).

The matching-to-sample task also allows for a comparison of the categorization of animates (i.e., trials with an animate sample) separate from inanimates (i.e., trials with an inanimate sample). It was predicted that children with HF-ASD would be impaired in forming animate, but not inanimate categories. A 2 (Group) × 2 (A–I Sample) repeated measures ANOVA, revealed no main effect for Group, but a trend main effect for A–I Sample, $F(1, 34) = 3.05$, $p = .08$, partial $\eta^2 = .08$, whereby both HF-ASD and TD children categorized animates ($M = 74\%$) better than inanimates ($M = 61\%$). The Group × A–I Sample interaction was not significant, $F(1,34) = .73$, $p = .40$, partial $\eta^2 = .02$.

An analysis of the RTs obtained on the animate–inanimate trials of the matching-to-sample task indicating that TD and HF-ASD groups responded equally fast (HF-ASD $M = 4{,}280$ ms; TD $M = 5{,}476$ ms), $F(1,29) = 1.26$ $p = .27$, partial $\eta^2 = .04$. Furthermore, no main effect of A–I Sample, $F(1,29) = 2.83$, $p = .10$, $\eta^2 = .09$, or Group × A–I Sample interaction, $F(1,29) = .17$, $p = .69$, partial $\eta^2 = .01$, was found.

Finally, the quantity and quality of verbal responses describing the categories children created in the object sorting task were analyzed for both HF-ASD and TD groups. The number of children who did not provide a verbal response was equivalent across HF-ASD ($n = 5$) and TD ($n = 4$) groups, $X^2 = .24$, $p = .63$. Chi square analyses for the proportion of children who provided each type of response (e.g., taxonomic, thematic, perceptual) on at least one occasion are shown in Table 2, while Table 3 shows the mean percentage of trials children adopted either a taxonomic or thematic sorting strategy.

3.3. Relation between attention to biological motion and categorization

Pearson product-moment correlation coefficients were computed to explore the potential link between attention to biological motion and the ability to form animate categories, or conversely attention to inanimate motion and the ability to form inanimate categories, among TD children and children with HF-ASD. Bonferroni correction for multiple comparisons was applied for correlations computed using each categorization variable (e.g., animate and inanimate matching-to-sample performance was correlated with three biological motion variables, thus alpha of .05 was divided by 3 to produce a corrected alpha of .02). For both HF-ASD and TD groups, we expected a positive correlation between attention to biological motion (orienting, preference) and the ability to form animate categories. We first computed correlations using the combined HF-ASD and TD group to investigate this hypothesis, before examining whether the potential relation differed for each group individually. Using the combined groups, orienting toward biological motion was not significantly related to children's ability to form categories on either the matching-to-sample, $r(34) = -.09$, $p = .59$, or object sorting task, $r(34) = .03$, $p = .85$. This same pattern of findings was maintained when correlations were computed among HF-ASD and TD groups individually.

Across groups, we reasoned that visual exploration of both animate and inanimate motion (i.e., total number of saccades) would positively correlate with A–I categorization performance (total score) on both the matching-to-sample and object sorting task. Applying Bonferroni correction for multiple comparisons (i.e., matching-to-sample and object sorting) produced a corrected alpha of 0.03. Interestingly, among children with HF-ASD increased visual exploration was positively correlated with A–I categorization abilities on the matching-to-sample task, $r(16) = .51$, $p = .03$, and tended to relate to performance on the object sorting task, $r(16) = .43$, $p = .08$. Thus, the active process of comparing animate and inanimate motion was related to the concurrent ability to form animate and inanimate categories. However, among TD children, individual differences in visual exploration of the motion stimuli was not related to A–I categorization ability on either matching-to-sample or object sorting task, p's > .50.

3.4. Correlations with age and IQ

Pearson product-moment correlations were computed to investigate whether chronological age, verbal, and non-verbal, cognitive abilities were related to attention toward biological versus non-biological motion and/or animate–inanimate categorization abilities among TD children and children with HF-ASD. Bonferroni correction for multiple comparisons was applied for correlations (e.g., corrected alpha for two categorization analyses was .03, and corrected alpha for three biological motion analyses was .02).

Table 2
Percentage of children's verbal responses on the object sorting task.

	HF-ASD *M* (SD)	TD *M* (SD)	$X^2(1,35)$	*p*
Taxonomic	35%	33%	.02	.90
Thematic	41%	39%	.02	.89
Perceptual	24%	39%	.96	.33

Note: Percentage of children providing each type of response does not add up to 100% because children were permitted to provide more than one verbal response describing the category. $n = 18$ per group.

Table 3
Type of sorting strategy used by children on the object sorting task.

	HF-ASD *M* (%)	TD *M* (%)
Taxonomic	69	47
Thematic	31	53

Note: $n = 18$ subjects per group each completed two categorization trials, thus, the mean percentage is a percentage of trials, rather than a percentage of children.
X^2 (2,71) = 3.32, $p = .07$.

Among TD children, chronological age was correlated with object sorting categorization performance, $r(16) = .76$, $p < .01$, but not with performance on matching-to-sample or any of the dependent variables measuring attention to biological motion (p's > .10). Among children with HF-ASD, chronological age was correlated with performance on the matching-to-sample categorization, $r(16) = .53$, $p = .03$, but was not related to performance on the object sorting task or any of the biological motion variables (p's > .10).

Among TD children, verbal IQ was correlated with increased attention to biological motion, $r(16) = .57$, $p = .01$, but not orienting toward biological motion or visual exploration (p's > .50). TD children's verbal and nonverbal IQ was also not related to performance on either the matching-to-sample or object sorting categorization tasks (p's > .10). Nonverbal IQ was not correlated with any of the biological motion variables, $p > .10$. Among children with HF-ASD, neither verbal nor nonverbal IQ was significantly correlated with the attention to biological motion variables (p's > .05), or performance on either the matching-to-sample or object sorting categorization task (p's > .05).

4. Discussion

Research investigating children's preferential attention and orienting toward social, compared to nonsocial, stimuli generally point to early impairments in social attention in children with ASD (Dawson, Meltzoff, Osterling, Rinaldi, & Brown, 1998; Webb et al., 2010; Chevallier, Kohls, Troiani, Brodkin, & Schultz, 2012). However, some studies have shown remediation of these deficits by adolescence (Cleary, Looney, Brady, & Fitzgerald, 2013; Freitag et al., 2008; Hubert et al., 2007; Rutherford & Troje, 2012; Saygin, Cook, & Blakemore, 2010), and more recently, among pre-adolescent children with ASD (Flanagan, Brodeur, & Burack, 2015). In the present study, a low-level measure of social attention, biological motion preference, was tested in younger school-age children with HF-ASD. In this study, we also wished to examine whether deficits in attention to biological motion, if found, were related to a broader deficits in the formation of the animacy concept.

That children with HF-ASD failed to preferentially attend to biological motion stimuli is consistent with previous research showing a non-preference for animate stimuli (Falck-Ytter et al., 2013; Klin et al., 2009); however, the performance of the TD children was unexpected. Specifically, TD children attended to inanimate motion more than animate motion. Overall, the pattern of behavior most consistent with TD children's performance included an initial orienting response toward biological motion, followed by a switch in attentional focus toward the inanimate motion. One probable explanation for these findings is that TD children spent more time looking at inanimate motion because this type of motion has been shown to be more difficult to identify in point light display (Wright, Kelley, & Poulin-Dubois, 2014). Relatedly, it is conceivable that children with HF-ASD looked comparatively longer at the biological motion as processing this type of motion was not as automatic as it was for TD children. Furthermore, although it is possible that TD children demonstrated more visual interest toward the inanimate stimuli because these stimuli repeated less frequently (two times) in comparison to the animate stimuli, (three times), a comparison of attention toward the animate stimuli on the first ($M = .38$) versus third ($M = .44$) presentation indicated that this was not the case. Interestingly, Chevallier et al. (2015) also found that TD adolescents looked longer at nonsocial static and dynamic stimuli compared with animate stimuli, and only showed a visual preference for dynamic social stimuli when presented in an interactive context. Thus, it is possible that the use of visual preference for biological motion as an indicator of social motivation may not parallel results of more naturalistic measures such as dynamic interactions (Chevallier et al., 2015), or measures that include children's circumscribed interests (Sasson, Ellison, Turner-Brown, Ditcher, & Bodfish, 2011; Sasson & Touchstone, 2013).

In contrast to previous research, our methodology did not involve habituation or prolonged exposure to the same-stimuli pairings, but rather presented novel pairings on each trial. Previous research showing a preference for animate motion in typical development have used designs where the participant was habituated to animate stimuli that was paired with scrambled, rigid, or inverted versions of the same stimuli (Bardi et al., 2010; Simion et al., 2008). Other research investigating visual preference in children with ASD also contrasted animate motion stimuli with inverted displays of the same stimuli played backwards (Falck-Ytter et al., 2013; Klin et al., 2009). The motion contrasts used in the current experiment were selected to represent a more naturalistic contrast between the motion of animate entities and non-living things. Thus, the inanimate stimuli were not simply an inverted, or modified, display of the animate stimuli. To clarify whether the performance of the TD group was developmentally appropriate, an additional group of adults were tested. Results revealed that adults also demonstrated an initial orienting response toward biological motion, but no overall visual preference for biological motion, suggesting that the response style of the TD children was not atypical. The present study did not replicate previous research showing visual preference for biological motion among TD children; thus, the selection of what the biological motion stimulus is paired with seems to be of critical importance. Future research should aim to fully characterize the developmental trajectory of biological motion processing from infancy though to childhood and adolescence by testing the optimal parameters and limits of the visual preference task.

This research was the first to investigate how children with HF-ASD form animate and inanimate categories. In the current experiment, a matching-to-sample task was administered to obtain a pure measure of animate–inanimate taxonomy, while an object sorting task allowed children to more flexibly form associations based on either taxonomic or thematic associations. Among children with HF-ASD, no deficits in the formation of animate or inanimate concepts were found. Furthermore, reaction time measures on the matching-to-sample task showed that children with HF-ASD were as fast as TD children in processing animate and inanimate conceptual relationships. In fact, on the object sorting task children with HF-ASD tended to outperform TD children in their ability to spontaneously sort animate and inanimate objects. This result is interpreted to be most likely due to the fact that TD children were more likely to switch to a thematic categorization strategy (e.g., placing humans in vehicles or on furniture) when given the opportunity, while children with HF-ASD preferred to maintain a taxonomic strategy. While it should certainly be acknowledged that these results were based on a relatively small sample size, we believe that they have face validity given that the performance of children with HF-ASD may be expected to reflect a greater preference for rule-based categorical decisions. We also reasoned that TD children's interest in pretend play might have motivated the switch to a thematic categorization strategy. It is also possible that children with ASD tended to outperform TD children on this task because they have received additional practice sorting and categorizing objects within their early intervention therapies. However, if this were the case, children with ASD would be expected to outperform TD children across all other categorization levels, which we did not observe. Results of the current study support previous research reporting that concepts related to biological knowledge may be intact among children with ASD (Peterson & Siegal, 1992).

A final exploratory aim of this study was to explore the potential link between individual differences in attention to animate and inanimate motion and children's concurrent performance on tasks measuring knowledge of animate and inanimate categories. Among both HF-ASD and TD groups, the hypothesis that increased attention, or preference for, biological motion would relate to children's ability to categorize animates was not supported. A number of possible factors might account for these null results. First, in contrast to evidence that biological motion facilitates categorization abilities in infancy (Poulin-Dubois, Crivello, & Wright, 2015), school-aged children's concept of animate and inanimate also includes other principles of naïve biology (e.g., capacity for growth, internal parts and thoughts: Massey & Gelman, 1988; Opfer & Gelman, 2010; Rhodes & Gelman, 2009). Therefore, unlike infants, young school-aged children, both with and without ASD, may no longer prioritize biological motion as a cue to animate class membership. Further, the analysis of children's gaze patterns suggest that among children with HF-ASD, the active process of comparing animate and inanimate motion through visual exploration was related to increased categorization performance, while measures of overall visual attention were not. Additionally, these results cannot be explained in terms of a more general difficulty with gaze shifting, or attentional disengagement (i.e., 'sticky attention') (Elsabbagh et al., 2013; Landry & Bryson, 2004; Zwaigenbaum et al., 2005) given that children with HF-ASD engaged in the same frequency of gaze shifting while watching the motion preference videos as TD children.

Future research in this area should adopt a developmental perspective to examine the relation between biological motion perception and the development of A–I categorization skills in both TD infants, infants at-risk for developing an ASD, as well as younger preschool children. An interesting future direction in this line of work would be to test a range of laboratory-based measures of social orienting (e.g., speech vs. non speech, static naturalistic scenes, dynamic faces vs. objects, etc.) to evaluate the consistency of social orienting measures, as well as identify the type of social orienting deficits that might best predict later social-cognitive skills. The potential utility of experimental measures of social attention has been suggested to be a measurable construct that may be used to define the level of social impairment observed in children with ASD (Dawson, Bernier & Ring, 2012). Following from this, it may be suggested that a battery of experimental tasks measuring relative changes in social attention may be a useful test of the social components of treatment success in early intervention programs. As this line of inquiry unfolds, it will be important to also investigate whether experimental measures of social orienting correlate with the frequency of social approach and social competence behaviors in children with ASD.

Acknowledgements

This research was supported by a grant from the Natural Sciences and Engineering Research Council of Canada (# 2003–2013) to Diane Poulin-Dubois. This research was also supported by NICHD under award #R01HD46805 to the last author and does not necessarily represent the views of the National Institutes of Health. We also wish to acknowledge the support provided by the Autism Research Training (ART) program, a Canadian Institute for Health Research (CIHR) Strategic Training initiative in autism research, as well as the Montreal Children's Hospital. Portions of this research were presented at the International Meeting for Autism Research (IMFAR), Atlanta, Georgia, USA. The authors would also like to thank Dr. Martha Arterberry and Dr. Nikolaus Troje for their contribution to the development of the point-light stimuli, Jenny Coutu who assisted with coding, as well as the dedicated families who participated.

References

Annaz, D., Campbell, R., Coleman, M., Milne, E., & Swettenham, J. (2012). Young children with autism spectrum disorder do not preferentially attend to biological motion. *Journal of Autism and Developmental Disorders*, *42*(3), 401–408. http://dx.doi.org/10.1007/s10803-011-1256-3.

Arterberry, M. E., & Bornstein, M. H. (2001). Three-month-old infants' categorization of animals and vehicles based on static and dynamic attributes. *Journal of Experimental Child Psychology*, *80*(4), 333–446. http://dx.doi.org/10.1006/jecp.2001.2637.

Bardi, L., Regolin, L., & Simion, F. (2010). Biological motion preference in humans at birth: role of dynamic and configural properties. *Developmental Science*, *2*, . http://dx.doi.org/10.1111/j.1467-7687.2010.00985.x.

Chevallier, C., Kohls, G., Troiani, V., Brodkin, E. S., & Schultz, R. T. (2012). The social motivation theory of autism. *Trends in Cognitive Sciences*, *16*(4), 231–239. http://dx.doi.org/10.1016/j.tics.2012.02.007.

Chevallier, C., Parish-Morris, J., McVey, A., Rump, K., Sasson, N., Herrington, J., et al. (2015). Measuring social attention and motivation in Autism Spectrum Disorder using eye-tracking: stimulus type matters. *Autism Research*. http://dx.doi.org/10.1002/aur.1479.

Cleary, L., Looney, K., Brady, N., & Fitzgerald, M. (2013). Inversion effects in the perception of the moving human form: a comparison of adolescents with autism spectrum disorder and typically developing adolescents. *Autism: The International Journal of Research and Practice*, *0*(0), 1–10. http://dx.doi.org/10.1177/1362361313499455.

Congiu, S., Schlottmann, A., & Ray, E. (2010). Unimpaired perception of social and physical causality, but impaired perception of animacy in high functioning children with autism. *Journal of Autism and Developmental Disorders*, *40*(1), 39–53. http://dx.doi.org/10.1007/s10803-009-0824-2.

Dawson, G., Bernier, R., & Ring, R. (2012). Social attention: a possible early indicator of efficacy in autism clinical trials. *Journal of Neurodevelopmental Disorders*, *4*(11) http://www.jneurodevdisorders.com/content/4/1/11.

Dawson, G., Meltzoff, A., Osterling, J., Rinaldi, J., & Brown, E. (1998). Children with autism fail to orient to naturally occurring social stimuli. *Journal of Autism and Developmental Disorders*, *28*(6), 479–485.

Elliott, C. (2007). Differential abilities scale, *Introductory and technical handbook*. 2nd ed. San Antonio, TX: The Psychological Corporation.

Elsabbagh, M., Fernandes, J., Webb, S. J., Dawson, G., Charman, T., & Johnson, M. H. (2013). Disengagement of visual attention in infancy is associated with emerging autism in toddlerhood. *Biological Psychiatry*, *74*(3), 189–194. http://dx.doi.org/10.1016/j.biopsych.2012.11.030.

Falck-Ytter, T., Rehnberg, E., & Bölte, S. (2013). Lack of visual orienting to biological motion and audiovisual synchrony in 3-year-olds with autism. *PLoS One*, *8* (7), e68816. http://dx.doi.org/10.1371/journal.pone.0068816.

Flanagan, T., Brodeur, D., & Burack, J. (2015). A point of departure in the comparison of social and nonsocial orienting among persons with Autism Spectrum Disorder. *Autism Research*. http://dx.doi.org/10.1002/aur1472.

Freitag, C. M., Konrad, C., Häberlen, M., Kleser, C., von Gontard, A., Reith, W., . . . Krick, C. (2008). Perception of biological motion in autism spectrum disorders. *Neuropsychologia*, *46*(5), 1480–1494. http://dx.doi.org/10.1016/j.neuropsychologia.2007.12.025.

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*(6), 1717–17129. http://dx.doi.org/10.1111/j.1467-8624.2006.00969.x.

Gelman, S., & Opfer, J. E. (2002). Development of the animate–inanimate distinction. In U. Goswami (Ed.), *Blackwell handbook of childhood cognitive development* (pp. 151–166).Blackwell Publishers Ltd..

Gelman, S., & Spelke, E. (1981). The development of thoughts about animate and inanimate objects: implications for research on social cognition. In J. H. Flavell, & L. Ross (Eds.), *Social cognitive development: frontiers and possible futures* (pp. 43–66).Cambridge, UK: Cambridge University Press.

Gottfried, G. M., & Gelman, S. (2005). Developing domain-specific causal-explanatory frameworks: the role of insides and immanence. *Cognitive Development*, *20*(1), 137–158. http://dx.doi.org/10.1016/j.cogdev.2004.07.003.

Happé, F., & Frith, U. (2006). The weak central coherence account: detail-focused cognitive style in Autism Spectrum Disorders. *Journal of Autism and Developmental Disorders*, *36*(1), 5–25.

Hubert, B., Wicker, B., Moore, D. G., Monfardini, E., Duverger, H., Da Fonséca, D., et al. (2007). Brief report: recognition of emotional and non-emotional biological motion in individuals with autistic spectrum disorders. *Journal of Autism and Developmental Disorders*, *37*(7), 1386–1392. http://dx.doi.org/10.1007/s10803-006-0275-y.

Inagaki, K., & Hatano, G. (1996). Young children's recognition of commonalities between animals and plants. *Child Development*, *67*(6), 2823–2840. http://dx.doi.org/10.2307/1131754.

Jipson, J. L., & Gelman, S. (2007). Robots and rodents: children's inferences about living and nonliving kinds. *Child Development*, *78*(6), 1675–1688.

Johnson, C., & Rakison, D. (2006). Early categorization of animate/inanimate concepts in young children with autism. *Journal of Developmental and Physical Disabilities*, *18*(2), 73–90. http://dx.doi.org/10.1007/s10882-006-9007-7.

Kagan, J., Moss, H., & Sigel, I. E. (1963). Psychological significance of styles of conceptualization. In J. Wright, & J. Kagan (Eds.), *Basic cognitive processes in children*Monographs of the Society for Research in Child Development.

Kaiser, M. D., & Pelphrey, K. (2012). Disrupted action perception in autism: behavioral evidence, neuroendophenotypes, and diagnostic utility. *Developmental Cognitive Neuroscience*, *2*(1), 25–35. http://dx.doi.org/10.1016/j.dcn.2011.05.005.

Klin, A., & Jones, W. (2006). Attributing social and physical meaning to ambiguous visual displays in individuals with higher-functioning autism spectrum disorders. *Brain and Cognition*, *61*, 40–53. http://dx.doi.org/10.1016/j.bandc.2005.12.016.

Klin, A., & Jones, W. (2008). Altered face scanning and impaired recognition of biological motion in a 15-month-old infant with autism. *Developmental Science*, *11*(1), 40–46.

Klin, A., Lin, D. J., Gorrindo, P., Ramsay, G., & Jones, W. (2009). Two-year-olds with autism orient to non-social contingencies rather than biological motion. *Nature*, *459*(7244), 257–261. http://dx.doi.org/10.1038/nature07868.

Klinger, L., & Dawson, G. (2001). Prototype formation in autism. *Development and Psychopathology*, *13*, 111–124.

Landry, R., & Bryson, S. (2004). Impaired disengagement of attention in young children with autism. *Journal of Child Psychology and Psychiatry*, *45*(6), 1115–1122. http://dx.doi.org/10.1111/j.1469-7610.2004.00304.x.

Lord, C., Risi, S., Lambrecht, L., Cook, E. H., Leventhal, B. L., DiLavore, P. C., . . . Rutter, M. (2000). Autism diagnostic observation schedule (ADOS). *Journal of Autism and Developmental Disorders*, *30*, 205–223 (Western Psychological Services) 10.1007/BF02211841.

Mandler, J. (1992). How to build a baby: II. Conceptual primitives. *Psychological Review*, *99*(4), 587–604.

Mangold International (2014). *Interact user guide, V. 10.0. ff.* Arnstorf: Mangold International.

Margett, T. E., & Witherington, D. C. (2011). The nature of preschoolers' concept of living and artificial objects. *Child Development*, *82*(6), 2067–2082. http://dx.doi.org/10.1111/j.1467-8624.2011.01661.x.

Markman, E. M., Cox, B., & Machida, S. (1981). The standard object-sorting task as a measure of conceptual organization. *Developmental Psychology*, *17*(1), 115–117. http://dx.doi.org/10.1037//0012-1649.17.1.115.

Massey, C. M., & Gelman, R. (1988). Preschooler's ability to decide whether a photographed unfamiliar object can move itself. *Developmental Psychology*, *24* (3), 307–317. http://dx.doi.org/10.1037//0012-1649.24.3.307.

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

Moore, D. G., Hobson, R. P., & Lee, A. (1997). Components of person perception: an investigation with autistic, non-autistic retarded and typically developing children and adolescents. *British Journal of Developmental Psychology*, *15*(4), 401–423. http://dx.doi.org/10.1111/j.2044-835X.1997.tb00738.x.

Murphy, P., Brady, N., Fitzgerald, M., & Troje, N. F. (2009). No evidence for impaired perception of biological motion in adults with autistic spectrum disorders. *Neuropsychologia*, *47*(14), 3225–3235. http://dx.doi.org/10.1016/j.neuropsychologia.2009.07.026.

Opfer, J. E., & Gelman, S. A. (2010). Development of the animate–inanimate distinction. In U. Goswami (Ed.), *The Wiley-Blackwell handbook of childhood cognitive development* (pp. 213–238).Wiley-Blackwell. http://dx.doi.org/10.1002/9780470996652.ch7.

Pavlova, M. (2011). Biological motion processing as a hallmark of social cognition. *Cerebral Cortex*, *22*(5), 981–995. http://dx.doi.org/10.1093/cercor/bhr156.

Pavlova, M. (2013). The development of biological motion processing in normalcy and pathology. In K. Johnson, & M. Shiffrar (Eds.), *People watching: social, perceptual and neurophysiological studies of body perception*New York, NY: Oxford University Press.

Peterson, C. C., & Siegal, M. (1992). Domain specificity and everyday biological, physical, and psychological thinking in normal, autistic, and deaf children. *New Directions in Child Development*, *75*, 55–70.

Pierce, K., Conant, D., Hazin, R., Stoner, R., & Desmond, J. (2011). Preference for geometric patterns early in life as a risk factor for autism. *Archives of General Psychiatry*, *68*(1), 101–109. http://dx.doi.org/10.1001/archgenpsychiatry.2010.113.

Poulin-Dubois, D., Crivello, C., & Wright, K. (2015). Biological motion primes the animate/inanimate distinction in infancy. *PLoS One*, *10*(2) . http://dx.doi.org/10.1371/journal.pone.0116910.

Rakison, D. H., & Poulin-Dubois, D. (2001). Developmental origin of the animate–inanimate distinction. *Psychological Bulletin*, *127*(2), 209–228.

Rhodes, M., & Gelman, S. A. (2009). Five-year-olds' beliefs about the discreteness of category boundaries for animals and artifacts. *Psychonomic Bulletin & Review*, *16*(5), 920–924. http://dx.doi.org/10.3758/PBR.16.5.920.

Rosch, E., & Mervis, C. (1975). Family resemblances: Studies in the internal structure of categories. *Cognitive Psychology*, *605*, 573–605.

Rutherford, M. D., Pennington, B., & Rogers, S. (2006). Perception of animacy in young children with autism. *Journal or Autism and Developmental Disorders*, *36*(8), 983–992. http://dx.doi.org/10.1007/s10803-006-0136-8.

Rutherford, M. D., & Troje, N. F. (2012). IQ predicts biological motion perception in autism spectrum disorders. *Journal of Autism and Developmental Disorders*, *42*(4), 557–565. http://dx.doi.org/10.1007/s10803-011-1267-0.

Rutter, M., Bailey, A., & Lord, C. (2003). *Social Communication Questionnaire. Los Angeles CA Western Psychological Services*. Los Angeles, CA: Western Psychological Services. http://www.hogrefe.co.uk/?/test/show/64/.

Sasson, N., Elison, J., Turner-Brown, L., Dichter, G., & Bodfish, J. (2011). Brief report: circumscribed attention in young children with autism. *Journal of Autism and Developmental Disorders*, *41*(2), 242–247. http://dx.doi.org/10.1007/s10803-010-1038-3.

Sasson, N., & Touchstone, E. (2013). Visual attention to competing social and object images by preschool children with autism spectrum disorder. *Journal of Autism and Developmental Disorders*. http://dx.doi.org/10.1007/s10803-013-1910-z.

Saygin, A. P., Cook, J., & Blakemore, S.-J. (2010). Unaffected perceptual thresholds for biological and non-biological form-from-motion perception in autism spectrum conditions. *PLoS One*, *5*(10), e13491. http://dx.doi.org/10.1371/journal.pone.0013491.

Schneider, W., Eschman, A., & Zuccolotto, A. (2002). *E-Prime users guide*. Pittsburgh: Psychology Software Tools Inc..

Shic, F., Bradshaw, J., Klin, A., Scassellati, B., & Chawarska, K. (2011). Limited activity monitoring in toddlers with autism spectrum disorder. *Brain Research*, *1380*, 246–254. http://dx.doi.org/10.1016/j.brainres.2010.11.074.

Shulman, C., Yirmiya, N., & Greenbaum, C. (1995). From categorization to classification: a comparison among individuals with autism mental retardation, and normal development. *Journal of Abnormal Psychology*, *104*(4), 601–609.

Sigel, I. E., Anderson, L. M., & Shapiro, H. (1966). Categorization behavior of lower- and middle-class negro preschool children: differences in dealing with representations of familiar objects. *Journal of Negro Education*, *35*(3), 218–229.

Simion, F., Regolin, L., & Bulf, H. (2008). A predisposition for biological motion in the newborn baby. *Proceedings of the National Academy of Sciences of the United States of America*, *105*(2), 809–813. http://dx.doi.org/10.1073/pnas.0707021105.

Soulières, I., Mottron, L., Giguere, G., & Larochelle, S. (2011). Category induction in autism: slower, perhaps different, but certainly possible. *The Quarterly Journal of Experimental Psychology*, *62*(2), 311–327.

Starkey, D. (1981). The origins of concept formation: Object sorting and object preference in early infancy. *Child Development*, *52*(2), 489–497.

Sugarman, S. (1983). Class grouping in space: provoked organization. *Children's early thought: developments in classification*. Cambridge, UK: Cambridge University Press69–84.

Swettenham, J., Baron-Cohen, S., Charman, T., Cox, A., Baird, G., Drew, A., . . . Wheelright, S. (1998). The frequency and distribution of spontaneous attention shifts between social and nonsocial stimuli in autistic, typically developing, and nonautistic developmentally delayed infants. *Journal of Child Psychology and Psychiatry*, *39*(5), 747–753.

Troje, N. F. (2002). Decomposing biological motion: a framework for analysis and synthesis of human gait patterns. *Journal of Vision*, *2*(5), 371–387. http://dx.doi.org/10.1167/2.5.2.

Uyeda, K. M., & Mandler, G. (1980). Prototypicality norms for 28 semantic categories. *Behavior Research Methods & Instrumentation*, *12*(6), 587–595.

Webb, S. J., Jones, E. J. H., Merkle, K., Namkung, J., Toth, K., Greenson, J., . . . Dawson, G. (2010). Toddlers with elevated autism symptoms show slowed habituation to faces. *Child Neuropsychology*, *16*, 255–278. http://dx.doi.org/10.1080/09297041003601454.

Wright, K., Kelley, E., & Poulin-Dubois, D. (2014). Schematic and realistic biological motion identification in children with high-functioning autism. *Research in Autism Spectrum Disorders*, *8*, 1394–1404. http://dx.doi.org/10.1016/j.rasd.2014.07.005.

Wright, K., Poulin-Dubois, D., & Kelley, E. (2015). The animate–inanimate distinction in preschool children. *The British Journal of Developmental Psychology*, *33*, 73–91. http://dx.doi.org/10.1111/bjdp.12068.

Zwaigenbaum, L., Bryson, S., Rogers, T., Roberts, W., Brian, J., & Szatmari, P. (2005). Behavioral manifestations of autism in the first year of life. *International Journal of Developmental Neuroscience*, *23*, 143–152.