Gist perception in adolescents with and without ASD: Ultra-rapid categorization of meaningful real-life scenes

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Abstract

Previous research has suggested the presence of a reduced preference to report and spontaneously interpret the global properties of a scene picture in adults with Autism Spectrum Disorder (ASD). Contrary to what is seen in typically developing (TD) participants, gist perception in ASD seems to occur mostly in a more explicit manner with focused attention. The current study used a set of non-social and social ultra-rapid categorization tasks to investigate gist perception in adolescents with and without ASD. When we instructed the participants to rapidly identify briefly presented object or scene information, we found that adolescents with ASD performed worse than TD participants. These findings complemented our previous study on ultra-rapid categorization in adults with or without ASD, in which no group-level differences in gist perception were observed. When categorization specifically entailed the fast processing of socially salient information, both adolescents and adults with ASD performed worse than TD participants. The combination of these results suggests an age-dependent improvement in general categorization ability but more long-lasting difficulties in rapid social categorization in individuals with ASD. We suggest that the poorer general performance of adolescents with ASD results from a less efficient rapid processing of global semantic structure.

Keywords: Autism Spectrum Disorder; vision research; ultra-rapid categorization; Theory of Mind; Reverse Hierarchy Theory; developmental effects

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Highlights

- Less efficient (more explicit) categorization of gist information in ASD.
- Long-lasting difficulties in rapid social categorization in individuals with ASD.
- Age-dependent improvement in general categorization ability in ASD.

Introduction

At first my observations took an abstract and generalizing turn. I looked at the passengers in masses, and thought of them in their aggregate relations. Soon, however, I descended to details, and regarded with minute interest the innumerable varieties of figure, dress, air, gait, visage, and expression of countenance.

- from "The Man of the Crowd" (1845) by Edgar Allan Poe

In an ultra-rapid categorization paradigm (e.g., Rousselet, Joubert, & Fabre-Thorpe, 2005; Vanmarcke & Wagemans, 2015a), typically developing (TD) participants succeed at detecting the identity of the presented object or scene almost perfectly (even with 20 ms exposures). This suggests that our visual system can rapidly process a vast amount of perceptual information, and that TD participants have a tendency to process the overall Gestalt (gist) at the expense of details and surface features (Edgin & Pennington, 2005). Such natural tendency to quickly make sense of complex daily-life situations by extracting the gist of the scene, however, might not be equally strong in all individuals. Previous research has indicated that people with Autism Spectrum Disorder (ASD) are less inclined to process and use information at the level of overall structure and meaning. For instance, when making absolute categorical judgements, individuals with ASD show less inclination to use the overall average similarity of stimuli (Church et al., 2010). Moreover, category formation has been shown to develop atypically in children and adults with ASD (Edwards, Perlman, & Reed, 2012). More precisely, category formation in ASD will likely include a larger number of small-sized and exemplar-based categories than in their TD counterparts, not only with regard to non-social object and/or scene categorization, but also with respect to complex social situations (Motttron & Burack, 2006). Previous studies have indicated that individuals with ASD have problems in transferring sensory learning from one social context to another, generally leading to either situation-dependent or atypically generalized perceptual learning (Plaisted, 2001; Plaisted, O'Riordan, & Baron-Cohen, 1998). These problems in visual categorization, both in the categorization of objects in isolation (Blair, Frith, Smith, Abell, & Cipolotti, 2002) and in complex social situations (Chaminade, Fonseca, Rosset, Cheng, & Deruelle, 2015), may play a major role in the observed deficits in important cognitive

processes, such as social cognition, language comprehension, and rapid decision making, in people with ASD.

A recent meta-analysis on local/global processing (Van der Hallen et al., 2015) has indicated that individuals with ASD are generally slower in tasks requiring global processing, especially when local incongruent information is present in the stimulus. These differences in visual perception in ASD are generally captured by two competing neurocognitive frameworks. The first is the Weak Central Coherence hypothesis (WCC; Dakin & Frith, 2005), indicating that people typically have a tendency to process the overall Gestalt at the expense of details and surface features. It explains the performance of individuals with ASD as having a processing bias for local information coinciding with a failure to extract the more global aspects of the visual information. The presence of local or global processing demands will therefore predict their superior or inferior performance on a given task, respectively. In a revised version of the WCC account of visual processing in ASD, it is suggested that a reduced preference instead of an inability in global processing defines the differences in perception between people with or without ASD (Happé & Booth, 2008; Koldewyn, Jiang, Weigelt, & Kanwisher, 2013). In contrast with the WCC hypothesis, the Enhanced Perceptual Functioning (EPF) theory states that an overactivation of primary perceptual functions explains the focus of individuals with ASD on details (Mottron, Dawson, Soulières, Hubert, & Burack, 2006). It thereby stipulates an increased processing of local stimulus elements but not a failing or reduced global bias.

The current literature provides divergent evidence for both theories (Changizi, Hsieh, Nijhawan, Kanai, & Shimojo, 2008), implying the need for an overarching theoretical framework. One way to provide that theoretical backbone is by embedding the behavioral results into a coherent view of their corresponding neurological processes. By indicating timing and location of the different stages in visual perception in a modern view on the cortical hierarchy, a better understanding of these findings can be attained. We argue that such a view is offered by the Reverse Hierarchy Theory (RHT) (Hochstein & Ahissar, 2002; Ahissar & Hochstein, 2004). RHT is a perceptual theory in TD participants that dissociates early implicit from later explicit perception. Moreover, it dissociates the temporal early-late distinction from the structural distinction between low- and high-level areas in the brain. In particular, the theory proposes that visual processing goes through a fast feedforward sweep of processing to get a first rapid awareness of the conceptual gist of the scene. Following this first implicit perception, feedback connections then focus attention to specific low-level elements in the

display. This makes detailed visual information available for conscious awareness, leading to explicit 'vision with scrutiny'. This occurs at low-level visual areas since that is where the neural maps have retinotopy and neurons have sufficiently small receptive fields to capture the details. So, the two-stage theory indicates that initial scene perception is based on widely distributed attention identifying 'the forest before the trees', while later vision focuses attention to details in the display (trees, trunks, leaves, etc.). In addition to the classic structural hierarchy of low- and high-level areas, RHT proposes a reverse temporal hierarchy of early but high-level and late but low-level vision in TD participants. We thereby suggested that this early, high-level (global) processing is performed more slowly in people with ASD. This would suggest a slower gist extraction and thus slower and/or less accurate categorization and recognition of complex visual information in everyday life.

This hypothesis was tested in adults with and without ASD using an ultra-rapid categorization task with complex real-life scenes (Vanmarcke et al., 2016), but no group-level differences in performance were found when the task explicitly required a rapid visual gist identification. It is important to note, however, that this task was employed with clearly predefined task instructions and without perceptual masking of the stimulus information. When performing a free description open encoding task with masked stimulus presentation and less explicitly defined task instructions, adults with ASD did perform worse than their TD counterparts in rapidly extracting the global meaning (e.g., forest, desert,...) of a complex visual scene (Vanmarcke et al., *submitted*). Simultaneously, this study also indicated that participants with ASD were better than TD participants in providing correct object descriptions (e.g., chair, table,...) with longer presentation times, although no evidence was found to support the claim of an enhanced low-level feature detection in ASD. Taken together, these observations suggest the presence of a reduced implicit preference to rapidly report and interpret the global properties of a whole in people with ASD, in line with a recent study by Koldewyn and colleagues (2013). These subtle differences in the implicit processing underlying gist perception in ASD therefore suggest that the early, high-level global processing is generally preserved. In contradiction with TD adults, however, global processing seems to occur in a more explicit fashion requiring focused attention, especially when the presented stimuli or scenes require the fast processing of information about social relations and/or emotional understanding (Clark, Winkielman, McIntosh, & Daniel, 2008; Vanmarcke et al., 2016), such as the recognition of complex, briefly presented facial emotions (Golan, Baron-Cohen, Hill, & Rutherford, 2007). In the current study, we

assessed whether these findings on ultra-rapid non-social and social categorization in adults with and without ASD could be extended to a younger population of adolescents.

Goal 1: Gist perception in adolescents with ASD

Our first goal was to test the performance of adolescents with and without ASD in rapidly identifying the gist of a meaningful, real-life scene. In TD children, semantic categorization of visual information forms a fundamental perceptual and cognitive process which seems to undergo a specific developmental trajectory (Batty & Taylor, 2002). Previous results have thereby indicated that age has a significant impact on the ultra-rapid categorization of briefly presented objects and scenes in TD participants (Vanmarcke & Wagemans, 2015b). These age-related differences in early, high-level gist perception could be especially important with regard to the developmental course of categorization in people with ASD (Gastgeb & Strauss, 2012). Only a few studies on ASD have cross-sectionally examined categorization differences across the lifespan using natural categories and category members that varied in typicality (e.g., Gastgeb, Strauss, & Minshew, 2006; Newel, Best, Gastgeb, Rump, & Strauss, 2011). These studies clearly indicated that age was positively correlated with categorization ability, both in participants with and without ASD. Interestingly, this age-dependent improvement in performance was more pronounced for people with ASD. While adolescents with ASD performed worse compared to the TD adolescents, adults with ASD categorized more typical object category members equally efficient as their TD counterparts (Gastgeb & Strauss, 2012). The authors suggested that these outcomes followed from the conscious learning of certain category criteria or features allowing them to mimic TD performance in an unambiguous and predefined categorization task. This would suggest that more explicit, attention-focused extraction of the global meaning of a complex visual scene could be more effortful for younger people with ASD compared to adults with ASD. We hypothesized that this would translate in a worse and/or slower gist perception of meaningful real-life scenes in adolescents with ASD, compared to TD participants, on an explicit, ultra-rapid categorization task (*hypothesis 1*).

Goal 2: Social perception in adolescents with ASD

The second goal of the current study was to investigate whether adolescents with ASD were able to accurately detect an emotionally salient social interaction in an ultra-rapid categorization task.

Previous studies have reported a sharp age-related increase in visual exploration and a decrease in perseverative and detail-focused attention in both children with and without ASD (Elison, Sasson, Turner-Brown, Dichter, & Bodfish, 2012). This would suggest that an extended experience with real-life (non-)social sensory information is likely to affect categorization competence via an increased capacity to rapidly explore a complex array of visual information (Gauthier, Skudlarski, Gore, & Anderson, 2000; Johnson, 2001). These findings could be further related to research reporting an attentional bias in people with ASD, compared to TD participants, to non-social information from very early in life (Sasson, Turner-Brown, Holtzclaw, Lam, & Bodfish, 2008; Pierce, Conant, Hazin, Stoner, & Desmond, 2011). These differences in social attention between people with or without ASD are often rather subtle and only become more prominent in automatic, implicit measurements such as viewing preference based on the location of the first fixation (Fletcher-Watson, Leekam, Benson, Frank & Findlay, 2009). Previous research furthermore reported a decreased preferential attention to social objects and events (e.g., faces, people, and social actions) in individuals with ASD (for reviews, see Falck-Ytter & von Hofsten, 2011; Guillon, Hadjikhani, Baduel & Rogé, 2014). In addition, adults with ASD were only found to perform worse than TD participants when ultra-rapid categorization required the fast processing of socially relevant information (Vanmarcke et al., 2016). This was in line with previous findings indicating that the perceptual differences in performance between people with or without ASD were most pronounced with regard to the observation and interpretation of complex, socially relevant information (Baron-Cohen, 1995; Evers, Steyaert, Noens, & Wagemans, 2015). We therefore predicted that adolescents with ASD would perform especially worse and/or slower than TD adolescents when the ultra-rapid categorization task not only required the rapid extraction of global information but also the detection of an emotionally-salient social interaction in the images (*hypothesis 2*).

Goal 3: Ultra-rapid categorization: replication of central findings in adolescents with ASD

Previous research on ultra-rapid categorization in TD adolescent and adult participants has led to three main findings (for a more elaborate review, see Vanmarcke & Wagemans, 2015b).

(1) The level of categorization (basic versus superordinate object or scene categorization level): previous research consistently observed TD adolescents and adults to be faster at detecting superordinate-level information (e.g., object identification of categories such as ‘animal’ or ‘vehicle’

and scene identification of categories such as 'natural' or 'manmade') in comparison with detecting basic-level information (e.g., object identification of categories such as 'dog' or 'car' and scene identification of categories such as 'sea' or 'city') in a complex visual display (Batty & Taylor, 2002; Rousselet et al., 2005). A similar superordinate processing advantage was found in adults with and without ASD using an ultra-rapid categorization design (Vanmarcke et al., 2016). We predicted the relative differences in processing speed for the different levels of categorization to be stable across age and did not expect level of categorization to influence performance in adolescents with and without ASD differently (*hypothesis 3a*).

(2) The task goal (object versus scene categorization): previous research (e.g., Crouzet, Joubert, Thorpe, & Fabre-Thorpe, 2012; Vanmarcke & Wagemans, 2015b) has suggested that TD adolescents and adults are faster at detecting a superordinate object (e.g., animal, vehicle) embedded within a scene than to correctly categorize a superordinate scene (e.g., natural, artificial). Similar results were reported when administering a set of ultra-rapid categorization tasks from adults with ASD (Vanmarcke et al., 2016). This was in line with the observation that people with ASD, similar to the TD population, spontaneously use scene knowledge to modulate visual object processing (Bar, 2004; Van Eylen, De Graef, Steyaert, Wagemans, & Noens, 2013). We therefore predicted the task goal (object versus scene categorization) to affect performance of adolescents with and without ASD in a similar fashion (*hypothesis 3b*).

(3) The stimulus animacy (animate versus inanimate object or scene categorization): previous studies reported contradictory outcomes (animate versus inanimate processing advantage) in TD participants. While some studies did not observe an animacy effect (e.g., VanRullen & Thorpe, 2001), others provided evidence for an animate processing advantage (e.g., Crouzet, Kirchner & Thorpe, 2010) and some even provided evidence for an opposite, inanimate, processing advantage (e.g., Praß, Grimsen, König, & Fahle, 2013). In a previous study on ultra-rapid categorization we found that both adults with and without ASD showed a similar inanimate advantage, without any group-level differences (Vanmarcke et al., 2016). This was surprising, given the previously reported ASD-specific impairment in identifying animate object information (Burnett, Panis, Wagemans, & Jellema, 2014). A critical difference between both paradigms might be that the stimuli in the latter study were impoverished and only gradually changed to form the outline of an animate or inanimate object (exploiting a paradigm, first introduced by Evers, Panis, Torfs, Steyaert, Noens, & Wagemans,

2014). Given that the current study used a static ultra-rapid detection paradigm, we expected an inanimate advantage for all participants, with or without ASD (*hypothesis 3c*).

Methods and materials

Participants

A group of 27 adolescents (23 men, 4 women) with ASD (mean age = 13.78; $SD = 1.28$) and a TD control group (mean age = 13.26; $SD = 1.63$), which were individually matched on age, gender and IQ, participated in this study (see Table 1 for participant characteristics). IQ was estimated using an abbreviated four-subtest (Vocabulary, Similarities, Picture Completion and Block Design) version of the WISC-III (Sattler, 2001; Wechsler, 1997). All participants also completed the Dutch Social Responsiveness Scale (SRS) questionnaire (Roeyers, Thys, Druart, Schryver, & Schittekatte, 2011) to get an overall estimation of individual and/or group-level differences in ASD traits.

The control group was selected, solely based on the matching criteria, from a larger set of 48 TD participants of which the data have been previously published by Vanmarcke and Wagemans (2015b). Participants from the ASD group were previously diagnosed with a pervasive developmental disorder (Autistic Disorder, Asperger syndrome or PPD-NOS), according to DSM-IV-TR criteria (American Psychiatric Association, 2000), by a multidisciplinary team. Recruitment was exclusively set up via the Autism Expertise Centre of the University Hospital in Leuven. Furthermore, a trained clinical psychologist administered the Autism Diagnostic Observation Schedule (ADOS) module 3 (Lord, Rutter, Di Lavore, & Risi, 1999) from all participants with a clinical diagnosis. The individual ADOS results thereby confirmed the clinical diagnosis of our participants and, as a result, we reported the results of the full ASD group in the current study. All participants had normal or corrected-to-normal vision. The study was approved by the Medical Ethics Commission of KU Leuven and both the participants themselves and their parents provided written informed consent before onset of the experiment.

Computer tasks

Participants were tested on three different ultra-rapid categorization tasks, which provided the main corpus of our testing battery: (1) the behavioral baseline, (2) the animal/vehicle, and (3) the social

task. The first of these tasks, the behavioral baseline, controlled for general differences in performing simple rapid motor responses and categorical decisions, because previous research indicated an impaired execution and planning of motor behavior in people with ASD (Sacrey, Germani, Bryson, & Zwaigenbaum, 2014). An overview of the order of all tasks, tests and questionnaires is provided in the Supplementary materials.

In all computer tasks, participants were seated at 57 cm from the calibrated (gamma corrected) computer monitor (resolution: 1920 x 1200; refresh rate: 60 Hz; type: Monitor DELL U2410) in a dimly lit room. The head position of the participants was stabilized by means of a head and chin rest. Before commencing each of the three ultra-rapid categorization tasks, participants completed a brief practice session with visual trial-by-trial feedback (a green or red fixation cross after each correct or incorrect response, respectively) to familiarize them with the design (8 stimuli per test block; 50% targets). During the actual experiment no feedback was provided.

Behavioral baseline. The behavioral baseline task was included (Figure 1A), to test for differences in simple categorization decision making and concurrent motor responding. On each trial a fixation cross (apparent size: $1 \times 1^\circ$ of visual angle) appeared for 500 ms, followed by a briefly flashed (33 ms) image of either a black circle or triangle (average apparent size: $5 \times 5^\circ$). Participants were then given a 1000 ms response window to either answer (1) *Is there a triangle on the screen?* or (2) *Is there a circle on the screen?*. Half of the participants (balanced for ASD and gender) received the former question, while the other half responded to the latter. If the stimulus contained the target (go trial), participants were instructed to press the space bar as fast as possible. If no target was present (no-go trial), participants had to wait for the next stimulus to appear. The inter trial interval (ITI) was randomized within a range of 1000-1500 ms. A total of 100 stimuli were shown (50% targets; randomized order).

Animal/vehicle task. On each trial of the animal/vehicle task (Figure 1B) a fixation cross (apparent size: $1 \times 1^\circ$) appeared for 500 ms, followed by a briefly flashed (33 ms) and meaningful color picture (apparent size: $18 \times 12.5^\circ$). Next, participants were given a 1000 ms response window to answer one of the following six questions: (1) *Is the scene artificial (manmade)?*, (2) *Is the scene natural?*, (3) *Is there a vehicle in the scene?*, (4) *Is there an animal in the scene?*, (5) *Is there a car in the scene?* or (6) *Is there a dog in the scene?*. The task was divided in six consecutive blocks, each consisting of 100 stimuli, in which one of the different questions had to be answered (50% targets;

randomized order). All participants completed all six blocks (randomized testing order) and the ITI was randomized within a range of 1000-1500 ms.

Social task. In this task (Figure 1C) participants had to respond to the presentation of a meaningful color picture (apparent size: 28 x 19°). A fixation cross (apparent size: 1 x 1°) appeared for 500 ms, followed by the briefly flashed (83 ms) image. Participants received a 1000 ms response window to either answer (1) *Is the scene happening indoor?* or (2) *Is there a positive interaction (friendship) present in the scene?*. The task was divided in two consecutive blocks, each consisting of the same 100 stimuli (50% targets; randomized order). All participants completed both blocks (randomized testing order) and the ITI was randomized within a range of 1000-1500 ms.

Stimuli

The images in the short practice sessions (preceding the actual experiments) were different from those in the testing phase. Some examples of the used stimuli are shown in Figure 2. All images can be found on <http://gestaltrevision.be/en/resources/supplementary-material>.

Behavioral baseline. A set of 108 black, geometrical figures (mean luminance on the screen: 1-3 cd/m²) were created using the open-source software library PsychoPy, which is written in Python (Peirce, 2008). These images were either triangles ($n = 54$) or circles ($n = 54$) of different sizes (average size: 185 x 185 pixels; [min max] size: [136 234] x [136 234] pixels) and presented only once (either as target or non-target) during the experiment or practice session.

Animal/vehicle task. A set of 624 color images (650 x 460 pixels) was used for this task. These were selected as being unambiguously artificial ($n = 104$), natural ($n = 104$), vehicle ($n = 104$), animal ($n = 104$), car ($n = 104$) or dog ($n = 104$) pictures by unanimous consensus between several lab members (including the first author). They were only presented once (either as target or non-target) during the experiment or the practice session. In line with previous research (e.g., Praß et al., 2014), targets and non-targets of the same level of categorization were used in each stimulus category: at superordinate level both for ultra-rapid scene (natural/artificial) and object (animal/vehicle) categorization and at basic level only for ultra-rapid object (dog/car) categorization. Concretely: (1) natural stimuli were used as non-targets in the artificial category; (2) artificial stimuli were used as non-targets in the natural category; (3) animal stimuli were used as non-targets for the

vehicle category; (4) vehicle stimuli were used as non-targets for the animal category; (5) vehicle stimuli were used as non-targets in the car category; and finally, (6) animal stimuli were used as non-targets in the dog category. All images were set to the same global luminance and Root Mean Square (RMS) contrast (corresponding to a luminance distribution, within the RGB color spectrum, with a mean of [123.98; 128.00; 109.31] and a standard deviation (SD) of [24.13; 25.00; 25.02]) by computing the average luminance (mean luminance on the screen: 63-68 cd/m²) and RMS contrast across all images, to avoid low-level confounds.

Social task. A total set of 108 color images (1024 x 688 pixels) was used for this task. These were taken by the first author with a professional camera (Fujifilm FinePix S5 Pro) in different indoor (living room, kitchen, etc.) and outdoor (forest, meadow, etc.) settings. In each of these images, two people were depicted either interacting in a positive, in a negative, or in a neutral (absence of interaction) manner (treated as one single category). Ten separate raters, who did not participate in the actual study, scored the entire picture set on a scale from 1 (very negative) to 9 (very positive) to evaluate the effectiveness of the affective manipulation. These ratings were then used to select the final stimulus set. More precisely, each selected image depicting a positive interaction had a mean individual score above 7 (overall mean rating = 7.80; *SD* = .42), and the selected images depicting a negative or neutral interaction had a mean individual score below 5 (overall mean rating = 3.66; *SD* = .76). This final set was further divided in four different categories: (1) indoor and positive interaction (*n* = 27), (2) outdoor and positive interaction (*n* = 27), (3) indoor and negative/neutral interaction (*n* = 27) and (4) outdoor and negative/neutral interaction (*n* = 27). In both blocks the same stimuli were used and in all image categories a wide variety of possible social interactions was present. All images were set to the same global luminance and Root Mean Square (RMS) contrast (corresponding to a luminance distribution, within the RGB color spectrum, with a mean of [116.39; 110.00; 98.44] and a SD of [25.61; 25.00; 21.88]) by computing the average luminance (mean luminance on the screen: 33-38 cd/m²) and RMS contrast across all images.

Analyses

To evaluate possible group-level differences in the ultra-rapid categorization tasks, individual median RT and performance (accuracy), on each of the computer tasks, were used as dependent variables. For accuracy, this was operationalized by means of the sensitivity (*d'*) measure (Macmillan, &

Creelman, 1991). This monotonic function provides an indication of the performance for each observer, by combining the Hit (H) rate (proportion correctly judged go trials) with the False Alarm (FA) rate (proportion incorrectly judged no go trials) into a single standardized score: $d' = Z[H] - Z[FA]$. Within this framework, Z corresponds to the inverse of the normal distribution function. We first conducted an explorative mixed model ANOVA (with Greenhouse-Geisser (GG) correction if the sphericity assumption was violated (Greenhouse & Geisser, 1959)) with ASD (adolescents with or without ASD) as a between-subjects factor and computer Task (baseline, animal/vehicle and social task) as within-subjects factor. This resulted in a significant main effect of Task, a significant main effect of ASD and a significant ASD * Task interaction (see below). This latter interaction indicated that the categorization performance of people with and without ASD was differentially affected in the different computer tasks.

To investigate these task-related group-level differences more thoroughly, we then analyzed each of the computer tasks separately. More precisely, for each of these tasks the go response reaction time (RT) and accuracy (correct/incorrect) per trial were used as the dependent variables (DV) in a General Linear Modeling (GLM) approach (McCullagh, 1984). Deviance values were calculated for the different random intercepts (logistic) regression models, based on a maximum likelihood estimation of both dependent variables separately, on each of the computer tasks. By evaluating the drop in deviance (DiD), together with the Akaike (AIC; Akaike, 1973) and Bayesian Information Criterion (BIC; Schwartz, 1978) values (for overview, see Supplementary materials), the final model was selected. After model selection, the individual predictive value of each selected parameter was tested using (1) Welch's t-test with Satterthwaite approximation for the denominator degrees of freedom (McArdle, 1987) in the random intercepts regression analysis for RT and (2) Wald Z-tests (Wald, 1943) in the random intercepts logistic regression analysis (link function is $\text{logit}(p) = \log(p/(1-p))$) for accuracy. The choice for a logistic modelling of the accuracy data was based on the dichotomous nature of the trial-by-trial performance data of the DV. Participant was always regarded as random intercept and participant characteristics (e.g., FSIQ, SRS, gender and age) were tested as possible covariates. In the behavioral baseline task, only Age (in years) was regarded as a fixed effect in the final model. In the animal/vehicle task, ASD (adolescents with or without ASD), Age (in years), Level of categorization (Basic versus Superordinate), Goal (Object versus Scene) and individual median RT and sensitivity performance on the behavioral baseline task were kept as fixed effects in

the final model. This model also contained the Animacy * Goal interaction effect. In the social task, ASD (adolescents with or without ASD), Age (in years), State (Scene versus Social) and individual median RT and sensitivity performance on the behavioral baseline task were used as fixed effects in the final model. This model also contained the fixed State * ASD interaction effect. The random intercept in the final model always reflects the amount of (significant) interindividual variability. The goodness-of-fit measures (for overview, see Supplementary materials) for each of the parameter estimates (χ^2) in the final GLM model selections in the different ultra-rapid categorization tasks are also provided in the results section.

Furthermore, we also combined the RT data of the current adolescent participant group with the data acquired on the same tasks in an adult participant group (previously reported in Vanmarcke et al., 2016). We analyzed the adolescent and adult data of participants with and without ASD using similar random intercepts (logistic) regression models as described above. For an overview of the participant characteristics, the conducted analysis and model parameter estimates per computer task, see the Supplementary materials. All outcomes were obtained by using the lme4 package (Bates, 2005) of the statistical software program R version 3.1.1 (R core team, 2013).

Results

Overall group-level differences in ultra-rapid categorization (Figure 3)

In the first exploratory mixed ANOVA analysis of the data (Table 2), we were interested in determining whether ultra-rapid categorization performance was (or was not) differentially affected in adolescents with and without ASD (between-subjects factor) in three different categorization tasks (within-subjects factor): (1) a behavioral baseline, (2) a non-social categorization and (3) a social categorization task. With respect to individual median RT, our findings provided evidence for a main effect of Task ($F_{2;104} = 49.99$; $p < .001$; $\eta^2_p = .49$), a main effect of ASD ($F_{1;52} = 3.95$; $p = .05$; $\eta^2_p = .07$) and a significant ASD * Task interaction ($F_{2;104} = 3.97$; $p = .02$; $\eta^2_p = .07$). Although similar main effects of Task ($F_{1.46;75.91} = 248.03$; $p < .001$; $\eta^2_p = .83$) and ASD ($F_{1;52} = 7.14$; $p = .01$; $\eta^2_p = .12$) were also observed for performance accuracy (d'), only a tendency was found for the ASD * Task interaction ($F_{1.46;75.91} = 2.62$; $p = .09$; $\eta^2_p = .05$). Nonetheless, we concluded that the significant task-dependent group-level differences in individual median RT (and to a lesser extent in accuracy performance) in (non)social

ultra-rapid categorization, urged us to further analyze our findings for each of the computer tasks separately.

Ultra-rapid categorization in the behavioral baseline task

Focusing first on the behavioral baseline task, no evidence was found to support the hypothesis that ASD has an impact on basic ultra-rapid categorization decisions and motor performance in this baseline task (for the parameter estimates with 95% confidence intervals, see Table 3). This was in line with the (very similar) actual observed outcomes for TD adolescents (RT = 490 ms | Accuracy = 96.8 % correct) and adolescents with ASD (RT = 496 ms | Accuracy = 96.6 % correct). Adding other descriptive variables to the model did not significantly improve its predictive strength (neither for RT, nor for accuracy). Only adding Age (in years) as a predictor improved the model estimation of both RT ($t_{53.99} = -2.38$; $p = .02$; $P(\chi^2) < .05$) and accuracy ($Z = 2.67$; $p < .01$; $P(\chi^2) < .05$) performance significantly. In order to avoid any confounding age-dependent differences in basic ultra-rapid categorization decisions and motor performance, we calculated both median go response reaction time (RT) and sensitivity (d') values, per participant, for the ultra-rapid baseline task and included these as covariates in the analysis of the other ultra-rapid categorization tasks.

Ultra-rapid categorization in the non-social animal/vehicle task (Figure 4)

Performance in the behavioral baseline task proved to be a significant predictor of individual differences in both RT and accuracy in the animal/vehicle task (for the parameter estimates with 95% confidence intervals, see Table 4): people with higher median RT on the baseline task were faster in the animal/vehicle task ($t_{53.40} = 5.27$; $p < .001$; $P(\chi^2) < .01$) and higher accuracy in the baseline task lead to a more accurate non-social categorization performance ($Z = 2.28$; $p = .02$; $P(\chi^2) < .01$).

Goal 1: Gist perception in adolescents with ASD. We found a significant main effect of ASD for RT ($t_{52.80} = 2.12$; $p = .04$; $P(\chi^2) < .01$), and a tendency for accuracy ($Z = -1.89$; $p = .06$; $P(\chi^2) > .05$). This was in line with the actual observed outcomes for TD adolescents (RT = 529 ms | Accuracy = 92.5 % correct) and adolescents with ASD (RT = 560 ms | Accuracy = 89.5 % correct) and indicated that adolescents with ASD were slower (and slightly worse) in both ultra-rapid object and scene detection compared with TD participants (*hypothesis 1*). Furthermore, Age also had a significant

effect on RT ($t_{53.00} = -3.42$; $p < .01$; $P(\chi^2) < .01$): older participants performed generally better than younger participants. Nonetheless, no significant ASD * Age interaction was found.

Goal 3: Replication of central findings in adolescents with ASD. We found a significant main effect of Level of categorization (*hypothesis 3a*), both for RT ($t_{51.50} = -10.70$; $p < .001$; $P(\chi^2) < .001$) and accuracy ($Z = 9.56$; $p < .001$; $P(\chi^2) < .001$). This suggests that superordinate (more abstract) information (e.g., animal) was available earlier than basic (more concrete) level representations of its constituting subcategories (e.g., dog). No differences were observed between individuals with and without ASD on this variable. We also observed a significant main effect of Goal (*hypothesis 3b*), both for RT ($t_{53.30} = -$; $p < .001$; $P(\chi^2) < .001$) and accuracy ($Z = -5.86$; $p < .001$; $P(\chi^2) < .001$). This was a direct replication of the finding that participants are faster and more accurate in detecting a superordinate object (e.g., vehicle/animal) embedded within a scene than to correctly categorize a superordinate scene (e.g., artificial/natural) (e.g., Crouzet et al., 2012; Vanmarcke & Wagemans, 2015b). Finally, no significant main effect of Animacy (*hypothesis 3c*) was observed. However, we did find a significant Animacy * Goal interaction in RT ($t_{538.80} = 4.76$; $p < .001$; $P(\chi^2) < .01$). The latter finding indicated that an inanimate advantage only was present, when ultra-rapid categorization required participants to process information at a scene level.

Ultra-rapid categorization in the social task (Figure 5)

Performance in the behavioral baseline task proved to be a significant predictor of individual differences in both RT and accuracy in the social task (for the parameter estimates with 95% confidence intervals, see Table 5): while higher median reaction times on the baseline task lead to faster responses ($t_{53.83} = 3.86$; $p < .001$; $P(\chi^2) < .01$) in the social task, higher sensitivity scores lead to a more accurate performance ($Z = 3.35$; $p < .001$; $P(\chi^2) < .01$).

Goal 1: Gist perception in adolescents with ASD. We found a significant main effect of ASD in the social task, both for RT ($t_{53.91} = 3.10$; $p < .01$; $P(\chi^2) < .01$) and accuracy ($Z = -2.49$; $p = .01$; $P(\chi^2) < .05$). This was in line with the actual observed outcomes for TD adolescents (RT = 543 ms | Accuracy = 87.8 % correct) and adolescents with ASD (RT = 587 ms | Accuracy = 84.4 % correct) in the social task and was in line with the slower scene recognition in adolescents with ASD in the animal/vehicle task (see above, *hypothesis 1*). Furthermore, younger participants performed worse than older adolescents as indicated by the significant main effect of Age on RT ($t_{53.62} = -2.55$; $p = .01$).

Goal 2: Social perception in adolescents with ASD. We observed a significant main effect of State in the social task, both for RT ($t_{54.35} = -4.56$; $p < .001$; $P(\chi^2) < .001$) and accuracy ($Z = 8.01$; $p < .001$; $P(\chi^2) < .001$), suggesting that adolescents with and without ASD were significantly slower and worse in perceiving the social state (positive) than in identifying the scene state (indoor). However, this difficulty with rapidly categorizing the socially salient information was even more pronounced in participants with ASD, as indicated by a significant ASD * State interaction for RT ($t_{54.04} = -2.06$; $p = .04$; $P(\chi^2) < .01$). This was in line with the clear differences in performance observed for TD participants (RT = 576 ms | Accuracy = 82.3 % correct) and participants with ASD (RT = 643 ms | Accuracy = 78.1 % correct) in the social information condition of the task. The difference in performance of people with (RT = 532 ms | Accuracy = 90.8 % correct) and without (RT = 510 ms | Accuracy = 93.3 % correct) ASD in the non-social information condition was much less pronounced. Nonetheless, the model parameter estimates for the overall main effect of ASD, combined with the ASD * State interaction effect, indicated that the between-group level differences were significant for both conditions in the social task.

Age-related development of ultra-rapid categorization in ASD (Figure 6)

To further investigate the influence of age and ASD on categorization performance, we combined the RT data of the current adolescent participant group with the data acquired on the same tasks in an adult participant group (previously reported in Vanmarcke et al., 2016). Overall, we analyzed data from a group of 23 adolescents (19 men, 4 women) with ASD (mean age = 13.74; SD = 1.21), a TD adolescents group (mean age = 13.48; SD = 1.68), a group of 23 adults with ASD (mean age = 20.57; SD = 1.88) and a group of 23 TD adults (mean age = 20.83; SD = 2.06). These groups were matched on gender and IQ and, within both age ranges (adults and adolescents), also on age. For an overview of the conducted analysis and model parameter estimates per computer task, see the Supplementary materials.

Overall age-related differences in ultra-rapid categorization. We first conducted an exploratory mixed ANOVA analysis of the data, to determine whether ultra-rapid categorization performance was (or was not) differentially affected in adolescents and adults (Age: between-subjects-factor), with or without ASD (ASD: between-subjects factor), in three different categorization tasks (within-subjects factor): (1) a behavioral baseline, (2) a non-social categorization and (3) a

social categorization task. With respect to individual median RT, our findings provided evidence for a main effect of Task ($F_{1.85, 159.71} = 61.74$; $p < .001$; $\eta^2 = .41$), a main effect of ASD ($F_{1.88} = 5.10$; $p = .03$; $\eta^2 = .06$), a main effect of Age ($F_{1.88} = 10.64$; $p < .01$; $\eta^2 = .11$) and a significant Age * Task interaction ($F_{1.85, 159.71} = 19.77$; $p < .001$; $\eta^2 = .18$). We concluded that these significant task- and age-dependent differences in individual median RT in (non)social ultra-rapid categorization, urged us to further analyze our findings.

Goal 1: Gist perception in ASD. We found a significant main effect of ASD in both the animal/vehicle task ($t_{92.00} = 2.82$; $p < .01$; $P(\chi^2) < .01$) and the social task ($t_{100.72} = 2.77$; $p < .01$; $P(\chi^2) < .01$). This indicated that participants with ASD were slower (and worse) in both ultra-rapid object and scene recognition (*hypothesis 1*). The main effect of ASD in the animal/vehicle task (Figure 6a) was further characterized by a significant Age * ASD ($t_{92.00} = -2.66$; $p < .01$; $P(\chi^2) < .05$) interaction. The latter finding indicated that people with ASD are slower in extracting the gist of the scene during adolescence, but become better when growing older. We also found a significant main effect of ASD in the social task. The main effect of ASD in the social task (Figure 6b) was further characterized by two significant interaction effects: (1) ASD * Age ($t_{100.60} = -1.97$; $p = .05$; $P(\chi^2) < .001$) and (2) ASD * State ($t_{91.62} = ; p < .01$; $P(\chi^2) < .05$). In combination, these interactions are in line with the idea that people with ASD who grow older improve more in extracting global object and scene information than TD participants. This becomes particularly evident in the absence of a main effect of ASD in the adult participant group (see Vanmarcke et al., 2016).

Goal 2: Social perception in ASD. We observed a significant main effect of State ($t_{100.78} = -3.55$; $p < .001$; $P(\chi^2) < .001$) in the social task. This indicated that all participants with and without ASD were significantly slower in perceiving the social state (positive) than in identifying the scene state (indoor). These difficulties with rapidly categorizing the socially salient information were more pronounced in participants with ASD (*hypothesis 2*), as specified by a significant ASD * State interaction ($t_{91.62} = -3.06$; $p < .01$; $P(\chi^2) < .05$).

Goal 3: Central findings of ultra-rapid categorization in ASD. We found a significant main effect of Level of categorization (*hypothesis 3a*) for RT ($t_{94.60} = -3.54$; $p < .001$; $P(\chi^2) < .001$) in the animal/vehicle task. We also observed a significant main effect of Goal (*hypothesis 3b*) for RT ($t_{85.10} = 3.25$; $p < .01$; $P(\chi^2) < .001$) in the animal/vehicle task. The significant Age * Goal ($t_{85.70} = -2.24$; $p = .03$; $P(\chi^2) < .01$) RT interaction thereby indicated that scene-level categorization became increasingly

harder with age. No significant main effect of Animacy (*hypothesis 3c*) was observed in the animal/vehicle task. Nonetheless, we did observe a significant Animacy * Goal * Age three-way RT interaction ($t_{1085} = 11.05$; $p < .001$; $P(\chi^2) < .01$). This would suggest that problems with natural information mainly arises when scene level information is made available, especially at a later age.

Discussion

Goal 1: Gist perception in adolescents with ASD

The ASD group performed more slowly and worse at (non-social) ultra-rapid object and scene categorization than the TD control sample. This result is in favor of a general deficit in ultra-rapid gist perception of visual information in adolescents with ASD (*hypothesis 1*). This outcome is clearly different from our previous study on ultra-rapid categorization, in which no difference between adults with and without ASD was found (Vanmarcke et al., 2016). However, combining the new adolescent and the previously reported adult data (which used exactly the same tasks) revealed a significant Age * ASD interaction, suggesting an age-related improvement in response speed in the ultra-rapid gist perception of individuals with ASD (Gastgeb & Strauss, 2012). Although disentangling the specific feedforward and feedback processes involved in ultra-rapid object and scene categorization remains difficult based on behavioral testing alone (Joubert, Rousselet, Fabre-Thorpe, & Fize, 2009; Wichmann, Drewes, Rosas & Gegenfurtner, 2010), we attempt to interpret the main findings of the current study within the RHT framework of visual perception.

The rapid feedforward processing of visual information only interrupted ultra-rapid categorization in adolescents and not in adults with ASD. These age-dependent differences in gist perception are in line with previous research examining the development of categorization ability across the lifespan in people with and without ASD (Gastgeb & Strauss, 2012). Although age and categorization ability were positively correlated for all participants, this effect was more pronounced for children with ASD. The authors report that adolescents with ASD were still worse at categorizing typical object category members compared to the TD adolescents, while adults with and without ASD performed the task equally efficiently. In addition to the ongoing development of the motor system in children during adolescence, Batty and Taylor (2002) showed that changes in cognitive factors also specifically contributed to a slower categorization performance. In individuals with ASD, these

cognitive factors in categorization and concept formation seem to be delayed in younger children with ASD, as described by Johnson and Rakison (2006). These authors thereby suggested that children with ASD, similar to TD children, attend to dynamic relations that involve apparently causally connections (e.g., the link between legs and walking), but ignore other important relations that exist in the environment (e.g., things with legs also have eyes). This impaired performance on tasks requiring participants to attend to the interrelated nature of different complex stimulus elements in children with ASD (Brown & Bebko, 2012), can be contrasted with the enhanced ability of people with ASD to perceive and respond to differences in simple visual search displays (e.g., Joseph, Keehn, Connolly, Wolfe, & Horowitz, 2009; O’Riordan & Plaisted, 2001). Such an enhanced discrimination ability might lead older children and young adults with ASD to consciously memorize those low-level criteria or features critical for a correct category identification in a predefined categorization task (Gastgeb & Strauss, 2012). This age-related maturation of explicit object and scene categorization in people with ASD, could also be linked with the previously reported differences in functional brain connectivity between people with and without ASD (Dajana & Uddin, 2015). The majority of these studies focused on examining long-range functional connectivity aberrances in ASD (Kana, Libero, & Moore, 2011; Vissers, Cohen, & Geurts, 2012) and observed either hypo- or hyperconnectivity in children with ASD (Uddin, Supekar, & Menon, 2013). A recent study attempted to reconcile these conflicting results in the literature by proposing that hyper-connectivity of brain networks may be more characteristic of children with ASD, while hypo-connectivity may be more prevalent in older adolescents and adults with ASD (Just, Keller, Malave, Kana, & Varma, 2012). Furthermore, during all developmental stages lower local connectivity in sensory processing brain regions and higher local connectivity in complex information processing regions were observed in people with ASD (Dajana & Uddin, 2015). Higher local connectivity in ASD thereby corresponded to more severe ASD symptomatology and abnormal category formation in childhood (Supekar et al., 2013).

This dynamic interplay between perceptual abnormalities and neurological maturation in people with ASD, can be linked to the practice-induced improvement of perceptual learning in TD participants as described by RHT (Ahissar & Hochstein, 2004). The theory thereby assumes that learning is primarily driven by attentional priming, in which attention functions as the mechanism for choosing the relevant neuronal population by increasing its functional weight. Initial high-level learning must therefore precede low-level learning, as it provides the essential enabling stage for the

backward search process. Given the early-onset differences in attentional selection (Keehn, Müller, & Townsend, 2013) and category formation (Johnson & Rakison, 2006) in children with ASD, this perceptual learning seems to develop abnormally compared to TD children. This corresponds to the developmental differences in functional brain connectivity between children and adults with ASD (Dajana & Uddin, 2015; Just et al., 2012) and might allow people with ASD to develop explicit, compensatory mechanisms to overcome the interrupted early processing of gist information as observed in the current study (Belmonte & Yurgelun-Todd, 2003).

As a consequence, the findings from the current study can be linked to the revisited WCC account of visual processing in ASD (Happé & Booth, 2008), emphasizing a reduced preference in global processing (see also Koldewyn et al., 2013). More precisely, Koldewyn and colleagues (2013) argued that children with ASD showed strong interference from irrelevant global information in a local task, indicating that global processing is intact in ASD. These empirical observations within the scope of the 'local preference' hypothesis coincide with the tendency of people with ASD to use the overall average similarity of stimuli less when making absolute categorical judgments (Mottron & Burack, 2006). Especially with respect to complex social situations, this can lead to hyper-specific and extremely detailed categorization criteria in young children with ASD (Church et al., 2010). The implicit, rapid feedforward processing of information that is relevant for gist, as stipulated in RHT, will therefore be less efficient in children with ASD compared to TD participants, even when providing a clearly predefined categorization goal. People with ASD, without intellectual disability, will improve this categorization ability with age (Gastgeb & Strauss, 2012) and explicitly learn to solve the predefined categorization task correctly in adulthood (Vanmarcke et al., 2016). More precisely, the conscious learning of specific category criteria or features allows people with ASD to mimic TD performance in an unambiguous and predefined categorization task during adulthood (Pallett, Cohen, & Dopkins, 2014).

Finally, the current study does not allow to make strong theoretical claims about the later, more detailed feedback processing of visual information (Hochstein & Ahissar, 2002; Ahissar & Hochstein, 2004). The EPF account of visual perception (Mottron et al., 2006) thereby hypothesizes that these explicit and attentionally focused feedback connections in the visual cortex are enhanced in people with ASD. This is related to the observed tendency in people with ASD to perseverate on images/situations of interest, exploring them in a more detail-oriented manner (Sasson et al., 2008).

Furthermore, such a hyper-activation of detailed, but low-level, scene elements could explain the behavioral findings of superior perceptual discrimination and diminished processing of common features in people with ASD (Plaisted, 2001). We thereby believe that a less efficient (slower) early-stage and pre-attentive global processing of people with ASD can theoretically be combined with a later-stage advantage in the attention-focused processing of local scene (or object) elements. More precisely, we suggest that people with ASD are less efficient than TD participants in grasping the gist of a scene when presentation time is very brief, especially with regard to the pre-attentive rapid extraction of relevant object and scene information from a single glance (e.g., ultra-rapid categorization). When presentation / processing time gets longer, we believe that this initial processing delay in ASD becomes smaller (disappears). When participants then are required to consciously focus attention on local scene (object) information, people with ASD generally show an enhanced ability, compared to TD participants, to discriminate between locally defined stimuli embedded within a larger context (especially when gist perception is not central to the given task). In principle, it is also possible that the sequence of processing stages in which local and global aspects of an image are extracted is not always fixed in all tasks and observers. It is very well possible that the default mode of processing in TD perceivers is to extract the gist first, while task demands or individual differences may lead to processing modes in which one quickly changes to focusing on details if the task requires it (e.g., find Wally) or one focuses on details as the default mode of processing (e.g., some people with ASD). In order to test these theoretical claims, future research should focus on systematically manipulating the task design (e.g., presentation time, low-level confounds, etc.) and using other task paradigms (e.g., semantic priming, change blindness, etc.) with meaningful real-life scenes, while specifically focusing on different aspects of rapid, local information processing. Such psychophysical research will also have to focus on clarifying the defining (attentional) characteristics of rapid gist processing in ASD. For now, it remains an open question whether participants with ASD were generally worse in ultra-rapidly categorizing scene information than TD participants, or whether only the global gist elements of the scene were processed more slowly in ASD (while more detailed information about local elements in the image was perhaps retained equally well or better).

Goal 2: Social perception in adolescents with ASD

In line with other studies (e.g., Golan et al., 2006; Vanmarcke et al., 2016) using more ecologically valid stimuli, people with ASD experienced difficulties to extract the necessary information from complex social events. They were especially slower when ultra-rapid categorization involved the correct identification of a socially relevant situation as positive versus negative/neutral. These difficulties in flexibly integrating different sources of social, emotionally-salient, information has often been linked to deficits in Theory of mind (ToM) (Evers, 2014). ToM refers to the socio-cognitive ability to infer mental states of oneself and others implicitly, to interpret and understand their behaviors and to guide one's own actions accordingly (Baron-Cohen, 1995). The theory thereby describes a broad cluster of socio-communicative skills that are assumed to be generally impaired in people with ASD. A more recent reconceptualisation of ToM is the Enactive Mind hypothesis (Klin, Jones, Schultz & Volkmar, 2003). This hypothesis states that the autistic mind is not attuned to the social world, due to specific differences in social attention between people with or without ASD (Chevallier et al., 2015; Rajendran & Mitchell, 2007). These differences often remain subtle, but become more prominent in the preference of TD participants to look for social information during the first, automatic, saccadic eye-movement (Fletcher-Watson et al., 2009). This preference for social cues during the first eye-fixation was not observed in people with ASD, and suggested a lower attentional priority for social cues compared to the TD participants. As a consequence, Klin and colleagues (2003) suggested that people with ASD generally report relationships in terms of their physical properties, while TD participants look for social meaning even in the relation between geometric shapes (Rajendran & Mitchell, 2007). This might be related to the lower inclination of people with ASD to rapidly extract socially relevant information from a complex visual display (e.g., Koldewyn et al., 2013; Van der Hallen et al., 2015). While TD participants will often interpret a real-life situation based on a complex and interdependent interplay of several separate and emotionally-salient sources of information, people with ASD will be more likely to focus on the non-social physical properties of the scene (Chevallier et al., 2015). This would argue for a more specific problem with the fast processing and correct categorization of social relations in both children and adults with ASD (*hypothesis 2*).

Goal 3: Ultra-rapid categorization: replication of central findings in adolescents with ASD

Both for Level of categorization (*hypothesis 3a*) and Goal (*hypothesis 3b*) we found a significant main effect in both adolescents with and without ASD. This was in line with previous research on ultra-rapid

categorization in TD participants (e.g., Crouzet et al., 2012; for a more elaborate review, see Vanmarcke & Wagemans, 2015b). We did not find a significant main effect of Animacy (*hypothesis 3c*). The absence of an overall inanimate processing advantage was in contradiction to our expectations based on our previous findings in adults with and without ASD (e.g., Burnett et al., 2014; Vanmarcke & Wagemans, 2015). However, the significant Animacy * Goal interaction underlined the stimulus-dependency of findings on this variable, suggesting that problems with natural information mainly arises when scene level information is made available. In order to further quantify and understand the influence of Animacy on semantic object categorization in people with and without ASD, future research will need to focus on (1) quantifying the low-level image properties (e.g., complexity, orientation, and shape) of the selected stimulus set (Wichmann et al., 2010) and (2) benchmarking it based on the available information in the specific images (VanRullen, 2011).

Conclusion

This study provided evidence that adolescents with ASD, in contradiction to adults with and without ASD, performed slower than TD adolescents when explicitly identifying briefly presented objects and scenes. This would indicate a less efficient rapid feedforward processing of global semantic structure in younger people with ASD, characterized by an age-dependent improvement in categorization ability. People with ASD, without an intellectual disability, will therefore learn to explicitly solve the predefined categorization task correctly in adulthood.

With regard to the fast processing of information about social relations and/or emotional understanding, no age-related differences were observed. Both adolescents and adults with ASD performed especially worse than TD participants when categorization involved the processing of socially salient information.

Acknowledgements

This work was supported by the Research Foundation-Flanders (FWO) to Steven Vanmarcke and long-term structural funding by the Flemish Government (METH/14/02) to Johan Wagemans. The authors would like to thank Nadège Macé, Michelle Fabre-Thorpe and Simon Thorpe for providing us

with their stimulus material used in previous papers (e.g., Mace' et al. 2009). A substantial subset of these images was used in the animal/vehicle task. We also thank all participants for their time and contribution to this research.

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Figure captions

Figure 1. A graphical overview of the trial design of the ultra-rapid categorization tasks. The behavioral baseline (A) and animal/vehicle task (B) have the exact same layout with a presentation time of 33 ms. The social task (C) only differs in presentation time (83 ms). The inter-trial interval (ITI) between tasks varied between 1000-1500 ms.

Figure 2. A general overview of the type of images used within the scope of the different ultra-rapid categorization tasks. The complete picture set is available online on <http://gestaltrevision.be/en/resources/supplementary-material>.

Figure 3. Overview of individual median reaction time (A) and sensitivity, d' , (B) data in the ultra-rapid categorization tasks. The data are represented as the mean performance across participants, with error bars depicting the standard error of the mean (SEM). In (A) and (B), adolescents with ASD are depicted in blue and TD adolescents in red.

Figure 4. Overview of reaction time (A) and accuracy (B) data in the animal/vehicle ultra-rapid categorization task. The data are represented as the mean performance across participants, with error bars depicting the standard error of the mean (SEM). For accuracy, mean and SEM were calculated based on the logistic transformation of the values and then retransformed into percentage correct (%) data. In (A) and (B), adolescents with ASD are depicted in blue and TD adolescents in red.

Figure 5. Overview of reaction time (A) and accuracy (B) outcomes in the social ultra-rapid categorization task. The data are represented as the mean performance across participants, with error bars depicting the standard error of the mean (SEM). For accuracy, mean and SEM were calculated based on the logistic transformation of the values and then retransformed into percentage correct (%) data. In (A) and (B), adolescents with ASD are depicted in blue and TD adolescents in red.

Figure 6. Overview of the reaction time outcomes in the combined RT analysis of the adolescent and adult data in both (A) the animal/vehicle and (B) the social ultra-rapid categorization task. The data are represented as the mean performance across participants, with error bars depicting the standard error of the mean (SEM). In (A) and (B), adolescents with ASD are depicted in blue and TD adolescents in red. The dotted lines further depict the adults with ASD in dark purple and the TD adults in orange.

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6

Table 1. Overview of the average group-level performance (SD between brackets), for participants with ASD ($n = 27$) and TD participants ($n = 27$). On each of the descriptive tests separately, a one-way ANOVA with ASD as between-participants factor was conducted. When required, a Bonferroni correction for multiple comparisons was applied to avoid false positive results.

Variable	TD adolescents	ASD adolescents	TD vs ASD	Mean group-level difference?
Age	13.78 (1.28)	13.26 (1.63)	$F_{1,52} = 1.69$; $p = .20$; $\eta^2 = .03$	No
No group-level differences on age, given that both groups (ASD and TD participants) were matched on this variable.				
Full-Scale IQ	104.56 (9.51)	102.93 (9.35)	$F_{1,52} = .40$; $p = .53$; $\eta^2 = 7.76 * 10^{-3}$	No
Verbal IQ	106.44 (9.66)	101.85 (11.01)	$F_{1,52} = 2.65$; $p = .11$; $\eta^2 = .04$	No
Performal IQ	102.67 (12.11)	104.00 (14.79)	$F_{1,52} = .13$; $p = .72$; $\eta^2 = 2.52 * 10^{-3}$	No
No group-level differences on IQ, as that both groups (ASD and TD adolescents) were matched on this variable.				
SRS (Overall)	49.37 (9.08)	77.96 (12.73)	$F_{1,52} = 89.10$; $p < .001$; $\eta^2 = .62$	ASD > TD
SRS (Social consciousness)	46.67 (7.18)	66.42 (10.41)	$F_{1,52} = 65.06$; $p < .001$; $\eta^2 = .56$	ASD > TD
SRS (Social cognition)	50.19 (9.56)	76.35 (12.36)	$F_{1,52} = 74.62$; $p < .001$; $\eta^2 = .57$	ASD > TD
SRS (Social communication)	49.59 (8.52)	75.50 (14.53)	$F_{1,52} = 63.30$; $p < .001$; $\eta^2 = .55$	ASD > TD
SRS (Motivation)	48.74 (10.57)	69.46 (14.16)	$F_{1,52} = 36.36$; $p < .001$; $\eta^2 = .43$	ASD > TD
SRS (Preoccupation)	50.85 (9.29)	73.00 (14.29)	$F_{1,52} = 45.12$; $p < .001$; $\eta^2 = .45$	ASD > TD

The analysis indicated a significant main effect on the overall index score for ASD. When using the SRS as a quantitative ASD phenotype measure, the influence of behavior problems, age, and expressive language or cognitive level on scores must be considered (Hus, Bishop, Gotham, Huerta, & Lord, 2013). SRS scores are therefore best interpreted as indicating general levels of impairment. Nonetheless, adolescents with ASD scored clearly higher on the parent-report SRS questionnaire, measuring ASD-related behavior, compared to TD adolescents in the current study.

Note. Overview of the used abbreviations: WISC-III = Wechsler Intelligence Scale for Children-III, SRS = Social Responsiveness Scale, TD = Typically Developing.

Table 2. Overview of the mixed ANOVA analysis, for both median RT and mean accuracy, with ASD (adolescents with or without ASD) as a between-subjects factor and computer Task (baseline, animal/vehicle and social task) as within-subjects factor.

RT			
Parameter	F-statistic	p-value	Effect size (η^2_p)
Task	$F_{2,104} = 49.99$	$< .001$	.49
ASD	$F_{1,52} = 3.95$	.05	.07
Task * ASD	$F_{2,104} = 3.97$	.02	.07

Accuracy			
Parameter	F-statistic	p-value	Effect size (η^2_p)
Task	$F_{1.46,75.91} = 248.03$	$< .001$	.83
ASD	$F_{1,52} = 7.14$	.01	.12
Task * ASD	$F_{1.46,75.91} = 2.62$	.09	.05

Note. Overview of the used abbreviations: ASD = Autism Spectrum Disorder.

Table 3. Overview of the parameter estimates for the behavioral baseline task for both (a) the random intercepts regression analysis on the RT output and (b) the random intercepts logistic regression analysis on the accuracy data.

RT			
Parameter	Estimate (SE)	p-value	95% confidence interval
Intercept	.66 (.07)	< .001	[.52 ; .80]
Question	-.01 (.01)	.56	[-.03 ; .01]
Age	-.01 ($5 \cdot 10^{-3}$)	.43	[-.02 ; $-2 \cdot 10^{-4}$]
ASD	-.06 (.11)	.60	[-.28 ; .16]
ASD * Age	$-5 \cdot 10^{-3}$ ($8 \cdot 10^{-3}$)	.53	[-.02 ; .01]

Accuracy			
Parameter	Estimate (SE)	p-value	95% confidence interval
Intercept	-1.70 (1.79)	.34	[-5.21 ; 1.81]
Question	-.18 (.27)	.50	[-.71 ; .35]
Age	.37 (.14)	< .01	[.10 ; .64]
ASD	3.23 (2.71)	.23	[2.08 ; 8.54]
ASD * Age	-.26 (.20)	.19	[-.65 ; .13]

Note. Overview of the used abbreviations: ASD = Autism Spectrum Disorder.

Table 4. Overview of the parameter estimates for the animal/vehicle task for both (a) the random intercepts regression analysis on the RT output and (b) the random intercepts logistic regression analysis on the accuracy data.

RT			
Parameter	Estimate (SE)	p-value	95% CI
Intercept	.46 (.08)	< .001	[.30 ; .62]
Level of Categorization	-.048 (4*10 ⁻³)	< .001	[-.06 ; -.04]
Goal	.024 (6*10 ⁻³)	< .001	[-.04 ; -.01]
Age	-.015 (4*10 ⁻³)	< .01	[-.03 ; -.01]
ASD	.025 (.01)	.04	[.01 ; .05]
Median RT (baseline)	.64 (.12)	< .001	[.41 ; .88]
Sensitivity (baseline)	.01 (6*10 ⁻³)	.09	[-.01 ; .03]
Animacy * Goal	.023 (5*10 ⁻³)	< .001	[.01 ; .03]

Accuracy			
Parameter	Estimate (SE)	p-value	95% CI
Intercept	-.80 (1.03)	.43	[-2.10 ; 1.22]
Level of Categorization	1.28 (.13)	< .001	[1.16 ; 1.41]
Goal	-.86 (.15)	< .001	[-1.15 ; -.57]
Age	.04 (.06)	.51	[-.08 ; .16]
ASD	-.32 (.17)	.06	[-.65 ; .01]
Median RT (baseline)	1.72 (1.54)	.26	[-1.30 ; 4.74]
Sensitivity (baseline)	.22 (.10)	.02	[.02 ; .42]
Animacy * Goal	.05 (.11)	.62	[-.17 ; .27]

Note. Overview of the used abbreviations: ASD = Autism Spectrum Disorder, CI = Confidence Interval, RT = Reaction Time

Table 5. Overview of the parameter estimates for the Social task for both (a) the random intercepts regression analysis on the RT output and (b) the random intercepts logistic regression.

RT			
Parameter	Estimate (SE)	p-value	95% CI
Intercept	.56 (.09)	< .001	[.38 ; .74]
State	-.07 (.02)	< .001	[-.11 ; -.03]
Age	-.01 (4×10^{-3})	.01	[-.02 ; -2×10^{-3}]
ASD	.06 (.02)	< .01	[.02 ; .10]
Median RT (baseline)	.54 (.14)	< .001	[.27 ; .81]
Sensitivity (baseline)	-2×10^{-3} (.01)	.75	[-.02 ; .02]
State * ASD	-.04 (.02)	.04	[-.08 ; -1×10^{-3}]

Accuracy			
Parameter	Estimate (SE)	p-value	95% CI
Intercept	-2.97 (1.07)	< .01	[-5.07 ; -.87]
State	1.36 (.17)	< .001	[1.03 ; 1.69]
Age	.14 (.06)	.02	[.02 ; .26]
ASD	-.47 (.19)	.01	[-.84 ; -.10]
Median RT (baseline)	1.41 (1.58)	.37	[-1.69 ; 4.51]
Sensitivity (baseline)	.28 (.08)	< .001	[.12 ; .44]
State * ASD	-.03 (.23)	.92	[-.48 ; .42]

Note. Overview of the used abbreviations: ASD = Autism Spectrum Disorder, CI = Confidence Interval, RT = Reaction Time