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Review article

Social attention in ASD: A review and meta-analysis of eye-tracking studies

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ABSTRACT

Determining whether social attention is reduced in Autism Spectrum Disorder (ASD) and what factors influence social attention is important to our theoretical understanding of developmental trajectories of ASD and to designing targeted interventions for ASD. This meta-analysis examines data from 38 articles that used eye-tracking methods to compare individuals with ASD and TD controls. In this paper, the impact of eight factors on the size of the effect for the difference in social attention between these two groups are evaluated: age, non-verbal IQ matching, verbal IQ matching, motion, social content, ecological validity, audio input and attention bids. Results show that individuals with ASD spend less time attending to social stimuli than typically developing (TD) controls, with a mean effect size of 0.55. Social attention in ASD was most impacted when stimuli had a high social content (showed more than one person). This meta-analysis provides an opportunity to survey the eye-tracking research on social attention in ASD and to outline potential future research directions, more specifically research of social attention in the context of stimuli with high social content.

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From infancy, typically developing (TD) individuals attend preferentially to social stimuli, such as people, faces and body motions (Gliga & Csibra, 2007; Goren, Sarty, & Wu, 1975; Vuilleumier, 2002, etc.). This attentional bias toward the social world is highly adaptive, since social attention allows one to have rich social experiences that are crucial for the development of social and communicative skills, for example, language acquisition or face and emotion recognition (Grelotti, Gauthier, & Schultz, 2002; Johnson, 2005; Schultz, 2005). These social skills are impaired in individuals with Autism Spectrum Disorders (ASD, Uljarevic & Hamilton, 2013; Weigelt, Koldewyn, & Kanwisher, 2012), which has led to the proposition that impairments specific to ASD could reflect cascading effects of reduced social attention (Chevallier, Kohls, Troiani, Brodkin, & Schultz, 2012; Dawson, Webb, & McPartland, 2005).

Eye-tracking technology has facilitated research targeting social attention and results from experimental studies correlate with measures of social impairment and with autism symptom severity. For example, studies have found that reduced attention to social stimuli or increased attention to non-social stimuli is correlated with behavioral measures of autism (Bird, Press, & Richardson, 2011; Chawarska, Macari, & Shic, 2012; Klin, Jones, Schultz, Volkmar, & Cohen, 2002, Shic, Bradshaw, Klin, Scassellati, & Chawarska, 2011).

Other skills, such as face processing and language are significantly correlated with measures of social attention as well. Parish-Morris et al. (2013) reported associations between face processing skills and attention to faces in children, and Tenenbaum, Amso, Abar, and Sheinkopf (2014) reported that attention to a speaker's mouth and eyes (as measured with eye-tracking) were predictive of faster recognition of words among children with ASD.

Finally, associations between atypical processing of social information (e.g. increased attention to the mouth vs. the eyes) and social impairment or language difficulties have also been found. Greater attention to the mouth has been associated with increased social adaptation (Klin et al., 2002) and communicative competence (Norbury et al., 2009). These results suggest that eye-tracking methods are promising for studying social attention in ASD.

Although social deficits are a hallmark of ASD, it remains an area of debate whether attention to non-social over social stimuli is part of the deficit. If children with ASD do not attend to social stimuli, this could lead to other problems in social interaction. So far no consensus has been reached on whether social attention is fundamentally reduced or absent in individuals with ASD, with some studies showing significantly diminished attention to social information in ASD compared to TD controls (Klin et al., 2002; Kirchner, Hatri, Heekeren, & Dziobek, 2011; Riby and Hancock, 2009a, 2009b; Riby, Hancock, Jones, & Hanley, 2013; Rice, Moriuchi, Jones, & Klin, 2012; Shi et al., 2015; Shic et al., 2011) while others show no differences (Birmingham, Cerf, & Adolphs, 2011; Freeth, Ropar, Chapman, & Mitchell, 2010; Freeth, Ropar, Mitchell, Chapman, & Loher, 2011; Kemner, van der Geest, Verbaten, & van Engeland, 2007; Kuhn, Kourkoulou, & Leekam, 2010; Marsh, Pearson, Ropar, & Hamilton, 2015; Nadig, Lee, Singh, Bosshart, & Ozonoff, 2010; Parish-Morris et al., 2013; van der Geest, Kemner, Camfferman, Verbaten, & van Engeland, 2002).

The results that find differences between the two groups suggest that social attention in ASD might be atypical at two levels: (1) attending to social vs. non-social stimuli might be reduced and (2) the way in which attention is deployed for processing the social stimuli might be atypical, with decreased attention to the eyes and increased attention to the mouth and body compared to TD individuals. However, the fact that results are mixed leaves the question open as to whether this is the case in all circumstances. The two levels of the problem, although related, have distinct implications and should be investigated in this order, since the first refers to the choice of attending to a social stimulus as a whole as compared to a non-social stimulus and the second refers to how that social stimulus is processed, what parts of it are attended to. The first level tells us about the interest in and preference for the social world, or more specifically for social stimuli when they compete with non-social stimuli in the environment. The second informs us about the strategies for extracting social information from those stimuli, which might differ based on the task at hand and might be more or less efficient (e.g. recognizing the identity of faces or recognizing emotions, or making sense of speech, or anticipating actions make different parts of the social stimulus more informative, sometimes the eyes, other times the mouth, etc.)

This meta-analysis addresses the more basic first question, of whether individuals with ASD do have the same preference for the social world as TD individuals. The goal of this meta-analysis is thus to investigate whether there is an overall significant difference in social attention between individuals with ASD and TD controls and to identify potential factors that influence the magnitude of this difference.

One of the first studies to show deficits in social attention in individuals with ASD was an eye-tracking study by Klin et al. (2002), who found that when watching a segment of the movie *Who is afraid of Virginia Wolf?*, adolescent participants with ASD spent significantly less time attending to people and more time attending to the background and to irrelevant objects in the scene. This result was replicated by several other studies. For example, Riby and Hancock (2009b) found that participants with ASD spent less time attending to faces when looking at pictures of social scenes. Wilson, Brock, and Palermo (2010) showed that while TD children spend proportionally more time looking at people than objects, the ASD group showed no difference in viewing times. Shic et al. (2011) found that toddlers with ASD pay less attention to the activities of others and focus more on background objects compared to typically developing children.

However, other studies have found no significant differences in social attention between individuals with ASD and TD controls. Kemner et al. (2007) found that both children with ASD and TD children spend similar amounts of time fixating on face drawings embedded in an array of distractors. Parish-Morris et al. (2013) presented, side-by-side, short movies of faces and objects. They found no ASD vs. TD group differences in the amount of attention children and adolescents in their study directed toward faces as opposed to objects. Finally, Kuhn et al. (2010), who hypothesized that ASD individuals would be less susceptible to a magic trick due to their reduced sensitivity to social cues, found that in fact they were more susceptible than TD controls and found no differences in the amount of time the two groups spent fixating on the magician's face and eyes.

Given these mixed results, the variety of stimuli used, and the different experimental procedures, it is important to know not just whether there is an overall difference in social attention between individuals with ASD and TD controls, but also the specific circumstances under which individuals with ASD show diminished social attention. For example when the stimuli are dynamic, motion processing is required and this processing might be impaired for individuals with ASD (Guillon, Hadjikhani, Baduel, & Rogé, 2014). However, to my knowledge, no study has analyzed the available experimental literature as a whole to extract quantitative evidence that could examine possible factors influencing social attention and rule out others. The studies investigating these proposed factors vary in their experimental design and, taken individually, lack the ability to present a comprehensive picture – thus the need for a systematic quantitative review of the literature.

The goal for this meta-analysis is to search for quantitative answers to the following two questions: (1) Do individuals with ASD show overall diminished social attention? (2) What are the factors that affect how they distribute their attention between social and non-social stimuli? This meta-analysis thus returns to the basic questions of whether, how much and in what situations do individuals with ASD prefer attending to social stimuli as opposed to non social stimuli, as compared with TD individuals, and seeks to provide quantitative evidence for or against some of the answers proposed in the literature. Better understanding of the allocation of social attention in ASD and the factors moderating it could have important implications not just for revealing the underlying mechanisms of social and communication impairments in ASD, but also for the design of efficient, targeted interventions for ASD.

1. Methods

1.1. Sample of studies

Studies for this meta-analysis were collected by searching the PubMed database for articles prior to July 27, 2015 using the following Boolean search phrase: ((ASD) OR (autism) OR (Asperger)) AND ((eye-tracking) OR (eye tracking) OR (eye gaze)).

From the initial sample of 371 articles, the studies meeting the following criteria were selected (see Fig. 1): (1) the article was an empirical study published in English; (2) the article compared the two groups of interest ASD and TD; (3) the study was an eye-tracking study; (4) the study presented social and non-social stimuli simultaneously; (5) the article reported results of looking time measures. A total of 38 studies met the criteria above.

1.2. Moderator variables

Several moderator variables were selected based on factors suggested in the literature as potentially influencing the allocation of social attention in ASD (for a summary see Table 1). The final set of moderator variables consists of:

Age. Using age as a variable can answer questions such as: is social attention diminished throughout development? Does reduced social attention emerge early in development or late, and what are the possible implications for the development of other social and communicative skills? As summarized above, studies have both found and not found differences in social attention at various ages. Selecting age as a moderator, made it possible to test for potential developmental patterns of social attention. Jones and Klin (2013) have shown that infants later diagnosed with ASD exhibit a mean decline in eye fixation from 2 to 6 months of age. Given the links between ASD symptoms and social attention, declines or increases in social attention across development could potentially explain impairments in communicative skills.

Verbal IQ matching & Non-verbal IQ matching. Studies differ in how they match their control group to the ASD group. A possible concern is that differences in social attention seen between individuals with ASD and TD controls are due to differences in non-verbal or verbal intelligence, and therefore are not specific to ASD. Norbury et al. (2009) found that matching on language level eliminated group differences in social attention. However, Klin et al. (2002) who matched the ASD and TD groups on the more stringent verbal IQ scores found significant differences between them. These variables code for whether the two groups were matched based on IQ or not: if the two groups were not statistically different in terms of their non-verbal or verbal IQ scores, they were coded as matched. When the studies only reported matching on overall IQ they were coded as matching on both the non-verbal and verbal IQ (four studies). This variable helps determine how specific differences in social attention are to ASD or how much they depend on non-verbal or verbal skills, respectively.

Motion. The motion variable in this paper coded for the presence of static vs. dynamic stimuli and their potential effect on social attention in ASD. The motivation behind this variable is given by the results obtained by Klin, Lin, Gorrindo, Ramsay, and Jones (2009) and Falck-Ytter, Rehnberg, and Bölte (2013) showing that children with ASD, as opposed to typically developing children, have no preference for watching biological motion. However, this insight is further complicated by conflicting results: Speer, Cook, McMahon, and Clark (2007) found that participants with ASD differ from typically

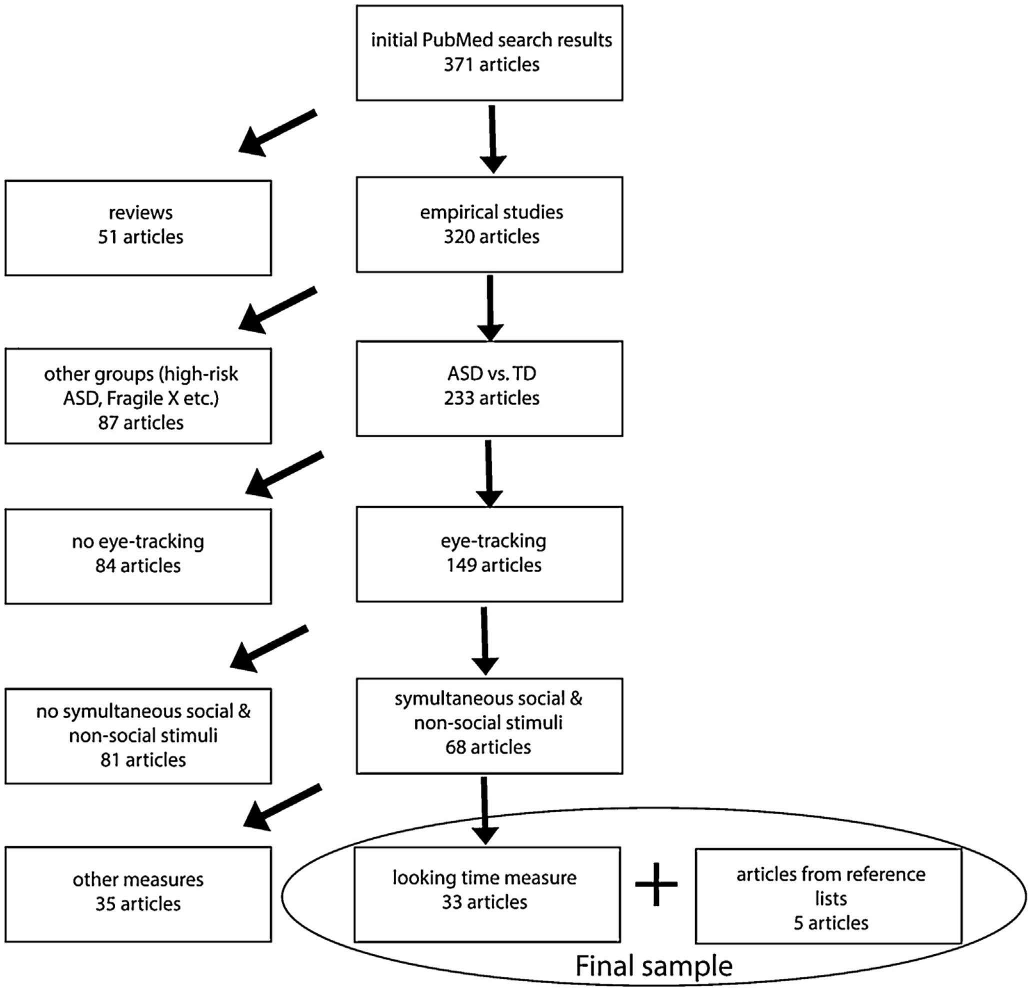

Fig. 1. Study selection process.

developing participants in their social attention for dynamic videos, but not for static photos of isolated individuals, whereas Riby and Hancock (2009b) found differences in attention for both static and dynamic stimuli. If motion in general, or some specific kind of motion (i.e. biological motion) were to moderate social attention, this would support the hypothesis that differences in social attention between ASD and TD individuals are driven by differences in bottom-up processing, rather than top-town mechanisms.

Social content. This moderator variable codes for whether the social stimuli presented contain one person or more people at least part of the time. The results of Hanley, McPhillips, Mulhern, and Riby (2013) suggest that social attention is allocated more similarly to TD controls when stimuli contain people presented in isolation but not as part of social scenes. This variable makes it possible to test whether children with ASD are sensitive to the richness of social

Table 1
Coding scheme for moderator variables.

Variable	Coded as 0	Coded as 1
Age	N/A	N/A
Non-verbal IQ matching	Not matched	Matched
Verbal IQ matching	Not matched	Matched
Motion	Static	Dynamic
Social content	Low (one person)	High (more people)
Ecological validity	Low (drawings, animations)	High (pictures, movies)
Audio input	Off	On
Attention bids	Absent (no direct speech)	Present (direct speech)

information conveyed by a scene, compared to TD individuals, and whether their attention is modulated by this top-down factor.

Ecological validity. This moderator variable codes for one aspect of ecological validity, namely whether the social stimulus is a drawing or cartoon, or whether it consists of realistic photographs or movies. The motivation for this variable is the discrepant results obtained by Riby and Hancock (2008), who used realistic photographs of people and found significant differences in social attention between individuals with ASD and TD individuals, and the results obtained by Kemner et al. (2007), who used schematic representations of faces and objects and found no differences between the two groups. The impact of this moderator on the difference in social attention between ASD and TD individuals may indicate whether ASD individuals have difficulty with processing complexity in a scene, a bottom-up attention modulator.

Audio input. The presence of an audio track in conjunction with visual presentation of social stimuli was chosen because of the results obtained by Klin et al. (2009), who found that children with ASD prefer to attend to audio–visual synchrony as compared to audio–visual mismatch, and Falck-Ytter et al. (2013), who found that individuals with ASD are impaired in processing audio–visual synchrony. This moderator allows us to further understand how the convergence of more sensory modalities affects the difference in social attention between ASD and TD individuals. The impact of this moderator could potentially suggest, either the presence of a facilitative effect of multi-sensory information on social attention, or on the contrary the increase of processing demands leading to disengagement for individuals with ASD.

Attention bids/Communicative intent. This variable codes for whether the social stimulus presented contained direct speech or not, for example if the actress in the movie being watched addressed the person watching by speaking directly toward the camera at least part of the time vs. movies where the actors do not speak directly to the camera. Chawarska et al. (2012) showed that, in conditions without eye contact or speech, ASD toddlers were comparable to TD ones in terms of social attention, but this was not the case when the social stimulus they watched had a communicative intent feature. This moderator tests for whether the nature of the situation (being interactive or not) affects the difference in the distribution of attention across the scene between ASD and TD individuals. It also tests whether direct bids for attention from others have a similar amount of power to capture the attention of ASD individuals as they do for TD individuals, or whether they have the opposite effect.

Other potentially relevant moderating factors, such as the salience of the non-social stimuli, could not be used due to insufficient reported data in the articles analyzed.

1.3. Dependent variables

Social attention was quantified as the mean percentage of time the subjects spent looking at the social (vs. the competing non-social) stimuli. Although this is not the only measure of social attention, and there is much merit to other measures of social attention as well (for examples of other measures see Guillon et al. (2014) and Ames and Fletcher-Watson (2010), it is by far the most widely and uniformly reported measure in eye-tracking studies and therefore the best candidate for a meta-analysis.

From the final sample of studies, means and standard deviations were recorded or *t*-values or *F*-values showing differences in looking time between the two groups (see Table 3). These statistics were used to compute Cohen's *d* effect sizes as a standardized measure of the difference between the TD and ASD groups (Field & Gillett, 2010). A positive Cohen's *d* effect size thus corresponds to a social attention impairment in the ASD group. Since these effect sizes are indicators of whether social attention is reduced in individuals with ASD relative to the TD controls, Cohen's *d* effect sizes were used as the dependent variable in the multivariate linear meta-regression analysis described below (see Table 4 for further details).

For studies that reported mean percentages of looking time at multiple social AOIs (areas of interest), the percentages were added. For example, if a study reported one mean percentage of looking time at faces and another mean percentage of looking time at bodies, the two means were added to form an overall percentage of looking time at social stimuli. The corresponding variances of the overall percentage of looking time at social stimuli was determined by combining the reported variances, with the correlation coefficients between the added variables computed using the standard multinomial distribution formula.

For studies that reported the mean looking time in milliseconds, the means were converted into percentages by dividing them by the total stimulus duration. When neither numerical values for means and standard deviations, nor *t*-values or *F*-values showing the difference in percentages of looking time between the two groups were reported in the manuscript, the authors were contacted to request this information. When the authors were unable to provide these numbers or when they did not respond, the values were measured from graphs (seven studies) using Adobe Illustrator CS6 and Adobe Photoshop CS6. As a check for the accuracy of graph measurements, they were compared with the original numbers (where both were available). There was only a slight discrepancy, affecting the effect size value by no more than 0.001, a difference so little that it was already effaced by rounding to two decimal places.

For the analyses the random-effects model recommended by Borenstein, Hedges, Higgins, and Rothstein (2010) was used to account for unexplained variance between the experiments, increasing the above-mentioned standard deviations using the DerSimonian and Laird formula (DerSimonian & Laird, 1986).

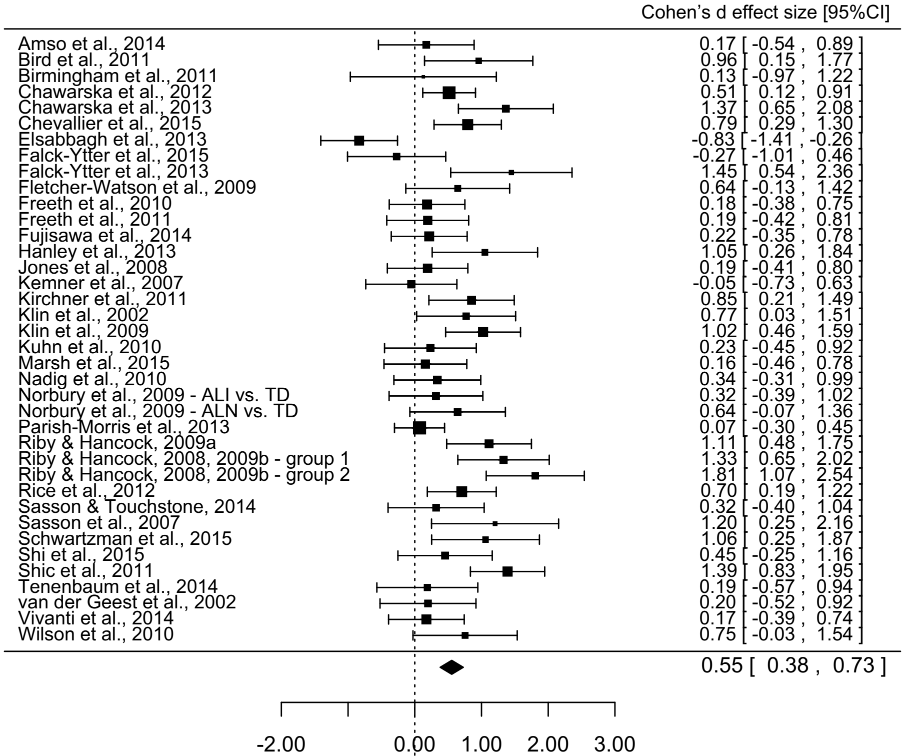

Fig. 2. Forest plot of social attention effect sizes with 95% confidence intervals.

1.4. Analyses

Two analyses of the effect size data were conducted. First, the overall effect size was calculated (see Fig. 2) to answer the general question of whether social attention is reduced in individuals with ASD as compared to TD controls. Second, the role of eight different moderator variables on the difference in social attention between the two groups was assessed through multivariate linear meta-regressions (see Tables 2 and 3) to answer the question of which factors lead to decreased social attention in ASD as opposed to TD controls.

All data were analyzed using R 3.1.2 (R Development Core Team, 2010) and the R package *metafor* 1.9-5 (Viechtbauer, 2010) and were weighted by the inverse variance of each study. To be conservative, one outlier study with very large positive effect size, about 5 standard deviations above the mean effect size (Riby et al., 2013), was excluded from the analyses.

When the studies reported data from different conditions separately, the conditions were treated as separate experiments (for a total of 53) in our regression analysis in order to better capture the impact of individual moderating factors on social attention. However, when calculating the overall effect size across all studies, the percentage of looking time to the social stimulus across conditions was instead averaged so as not to inflate the overall number of data points. For example the study by Chawarska et al. (2012) was treated as four different experiments (corresponding to the dyadic bid condition, the sandwich condition, the joint attention condition and the moving toys condition, which differ from each other based on the attention bids variable – the sandwich condition and the joint attention condition contain attention bids while the other two do not) for the multivariate regression analysis but as one aggregated effect size for computing the overall effect size across studies.

The same strategy was employed for dealing with studies that reported data separately for different groups. For example, the data from the two ASD groups reported by Norbury et al. (2009), matched on verbal IQ and not matched on verbal IQ, was treated as two separate experiments (distinguished by the moderating factor "verbal IQ") in the regression analysis, but as an aggregated effect size when computing the overall effect size across studies.

2. Results

2.1. Overall effect size

The random effects analysis of overall effect size indicated a mean effect size of 0.55, with 95% confidence limits from 0.38 to 0.73. This is a medium effect size (Cohen, 1988) and indicates that overall, individuals with autism spend less time than typically developing controls attending to social stimuli. Therefore, the general finding across studies is that social attention is

Table 2
Moderator variables.

Study	Age ASD years	Age TD	NVIQ matching	VIQ matching	Motion	Ecological validity	Social content	Audio input	Attention bids
Amso et al. (2014)	3.53 (1.06)	3.73 (1.03)	Not matched	Not matched	Static	High	Low	–	–
Bird et al. (2011)	40.5 (14.5)	32.8 (10.8)	Matched	Matched	Dynamic	High	High	On	Present
Birmingham et al. (2011)	31.6 (12.2)	32.6 (12.6)	Matched	Matched	Static	High	High	–	–
Chawarska et al. (2012) – dyadic bid	1.8 (0.24)	1.71 (0.25)	Not matched	Not matched	Dynamic	High	Low	On	Present
Chawarska et al. (2012) – joint attention	1.8 (0.24)	1.71 (0.25)	Not matched	Not matched	Dynamic	High	Low	On	Present
Chawarska et al. (2012) – moving toys	1.8 (0.24)	1.71 (0.25)	Not matched	Not matched	Dynamic	High	Low	On	Absent
Chawarska et al. (2012) – sandwitch	1.8 (0.24)	1.71 (0.25)	Not matched	Not matched	Dynamic	High	Low	On	Absent
Chawarska et al. (2013)	0.54 (0.06)	0.53 (0.03)	Not matched	Not matched	Dynamic	High	Low	On	Present
Chevallier et al. (2015) – dynamic task	12.3 (3.3)	14.9 (1.7)	Not matched	not matched	Dynamic	High	High	Off	Absent
Chevallier et al. (2015) – interactive task	12.3 (3.3)	14.9 (1.7)	Not matched	not matched	Dynamic	High	High	Off	Absent
Chevallier et al. (2015) – static task	12.3 (3.3)	14.9 (1.7)	Not matched	Not matched	Static	High	High	–	–
Elsabbagh et al. (2013) – 14 months	1.16	1.16	Not matched	Not matched	Static	High	Low	–	–
Elsabbagh et al. (2013) – 7 months	0.58	0.58	Not matched	Not matched	Static	High	Low	–	–
Falck-Ytter et al. (2013)	3.42 (0.44)	3.55 (0.43)	Matched	Not matched	Dynamic	Low	Low	On	Absent
Falck-Ytter et al. (2015)	6.7 (1.7)	6.9 (1.2)	Matched	Matched	Dynamic	High	Low	On	Present
Fletcher-Watson, Leekam, Benson, Frank, and Findlay (2009) – person	18.8 (2.3)	21.5 (7.8)	Matched	Not matched	Static	High	Low	–	–
Fletcher-Watson et al. (2009) – person present scene	18.8 (2.3)	21.5 (7.8)	Matched	Not matched	Static	High	Low	–	–
Freeth et al. (2010)	13.83 (1.37)	14 (1.37)	Matched	Matched	Static	High	Low	–	–
Freeth et al. (2011)	14.92 (1.4)	14.75 (1.3)	Not matched	Matched	Static	High	Low	–	–
Fujisawa, Tanaka, Saito, Kosaka, and Tomoda (2014) – biological motion	4.82 (1.13)	4 (1.89)	Not matched	Matched	Dynamic	Low	Low	Off	Absent
Fujisawa et al. (2014) – people and geometry	4.82 (1.13)	4 (1.89)	Not matched	Matched	Dynamic	High	High	Off	Absent
Hanley et al. (2013) – isolated faces	20.5	–	Matched	Matched	Static	High	low	–	–
Hanley et al. (2013) – social scenes	20.5	–	Matched	Matched	Static	High	High	–	–
Jones, Carr, and Klin (2008)	2.28 (0.58)	2.03 (0.68)	Matched	Not matched	Dynamic	High	Low	On	Present
Kemner et al. (2007)	10.4 (2.2)	10.3 (1.3)	Matched	Matched	Static	Low	Low	–	–
Kirchner et al. (2011)	31.9 (7.6)	31.8 (7.4)	Matched	Matched	Static	High	Low	–	–
Klin et al. (2009)	2.21 (0.54)	1.99 (0.66)	Matched	Not matched	Dynamic	Low	Low	On	Present
Klin et al. (2002)	15.4 (7.2)	17.9 (5.6)	Not matched	Matched	Dynamic	High	High	On	Absent
Kuhn et al. (2010)	19 (1.6)	21 (4.1)	Matched	Matched	Dynamic	High	Low	On	Absent
Marsh et al. (2015)	18.9 (4)	22 (6.1)	Matched	Matched	Dynamic	High	Low	Off	Absent
Nadig et al. (2010)	10.1 (1.5)	11 (1.11)	Matched	Matched	Dynamic	High	Low	On	Present
Norbury et al. (2009) – ALI vs. TD	14.9 (1.2)	14.5 (0.9)	Matched	Not matched	Dynamic	High	High	On	Absent
Norbury et al. (2009) – ALN vs. TD	14.9 (1.4)	14.5 (0.9)	Matched	Matched	Dynamic	High	High	On	Absent
Parish-Morris et al. (2013)	11.28 (2.89)	11.34 (3.04)	Matched	Not matched	Dynamic	High	Low	Off	Absent
Riby and Hancock (2008) – natural image; non-matched IQ	13.04 (2)	13.03 (4)	Not matched	Not matched	Static	High	High	–	–
Riby and Hancock (2008) – natural image; matched IQ	13.04 (2)	5.03 (1.42)	Matched	Not matched	Static	High	High	–	–
Riby and Hancock (2009a)	12.33	–	Matched	Not matched	Static	Low	Low	–	–
Riby and Hancock (2009b) – cartoon image; matched IQ	13.04 (2)	5.03 (1.42)	Matched	Not matched	Static	Low	High	–	–
Riby and Hancock (2009b) – cartoon image; non-matched IQ	13.04 (2)	13.03 (4)	Not matched	Not matched	Static	Low	High	–	–

Table 2 (*Continued*)

Study	Age ASD years	Age TD	NVIQ matching	VIQ matching	Motion	Ecological validity	Social content	Audio input	Attention bids
Riby and Hancock (2009b) – cartoon movie; matched IQ	13.04 (2)	5.03 (1.42)	Matched	Not matched	Dynamic	Low	High	On	Absent
Riby and Hancock (2009b) – cartoon movie; non-matched IQ	13.04 (2)	13.03 (4)	Not matched	Not matched	Dynamic	Low	High	On	Absent
Riby and Hancock (2009b) – natural movie; matched IQ	13.04 (2)	5.03 (1.42)	Matched	Not matched	Dynamic	High	High	On	Absent
Riby and Hancock (2009b) – natural movie; non-matched IQ	13.04 (2)	13.03 (4)	Not matched	Not matched	Dynamic	High	High	On	Absent
Rice et al. (2012)	10 (2.3)	9.5 (2.2)	Matched	Matched	Dynamic	High	High	On	Absent
Sasson and Touchstone (2014)	3.81 (0.93)	3.37 (0.81)	Not matched	Not matched	Static	High	Low	–	–
Sasson et al. (2007)	23 (5.27)	22.4 (6.26)	Matched	Matched	Static	High	High	–	–
Schwartzman, Velloso, D'Antino, and Santos (2015)	8.5 (4.4)	5.1 (0.9)	Not matched	Not matched	Static	High	Low	–	–
Shi et al. (2015)	5.07	4.84	Not matched	Matched	Dynamic	High	High	Off	Absent
Shic et al. (2011)	1.72 (0.25)	1.63 (0.23)	Not matched	Not matched	Dynamic	High	High	On	Absent
Tenenbaum et al. (2014)	3.6 (0.97)	1.36 (0.53)	Not matched	Matched	Dynamic	High	Low	On	Present
van der Geest et al. (2002)	10.6 (2.1)	9.9 (1.5)	Not matched	Not matched	Static	Low	Low	–	–
Vivanti, Trembath, and Dissanayake (2014)	3.88 (0.88)	3.69 (0.95)	Matched	Matched	Dynamic	High	Low	Off	Absent
Wilson et al. (2010)	10.13 (1.89)	10.65 (2.07)	Not matched	Not matched	Static	High	High	–	–

Table 3
Measure of average looking time to social stimuli and comparisons between ASD and TD groups.

Study and condition	N ASD	N TD	ASD looking time		TD looking time		*t*-Value	*F*-value
			Mean	SD	Mean	SD		
Amso et al. (2014)	15	15	25	11.62	27	11.62	–	–
Bird et al. (2011)	13	13	45	13	55	7	–	–
Birmingham et al. (2011)	9	5	56.77	15.91	58.83	16.42	–	–
Chawarska et al. (2012) – dyadic bid	54	48	63	17.98	73.5	11.14	–	–
Chawarska et al. (2012) – joint attention	54	48	80.9	10.68	85.1	7.54	–	–
Chawarska et al. (2012) – moving toys	54	48	18.9	12	16.5	8.41	–	–
Chawarska et al. (2012) – sandwitch	54	48	64.9	21.78	66.9	14.09	–	–
Chawarska et al. (2013)	12	35	55.27	10.7	64.91	5.38	–	–
Chevallier et al. (2015) – dynamic task	59	22	35	21	42	14	–	–
Chevallier et al. (2015) – interactive task	59	22	19	12	27	14	–	–
Chevallier et al. (2015) – static task	59	22	20	7	24	4	–	–
Elsabbagh et al. (2013) – 14 months	17	46	43	11.67	36.5	10.31	–	–
Elsabbagh et al. (2013) – 7 months	17	46	52.5	12.04	46.5	9.92	–	–
Falck-Ytter et al. (2013)	10	14	44.23	21.15	67.96	12.04	–	–
Falck-Ytter et al. (2015)	10	25	82.5	17.55	78.06	15.84	–	–
Fletcher-Watson et al. (2009) – person	12	15	27.2	12.44	33	10.83	–	–
Fletcher-Watson et al. (2009) – person present scene	12	15	55.4	7.6	58.9	9.4	–	–
Freeth et al. (2010)	24	24	–	–	–	–	–	0.39
Freeth et al. (2011)	20	21	–	–	–	–	0.62	–
Fujisawa et al. (2014) – biological motion	15	58	55.53	20.16	51.6	14.98	–	–
Fujisawa et al. (2014) – people and geometry	15	58	36.2	17.76	45	15.21	–	–
Hanley et al. (2013) – isolated faces	14	14	63.48	9.66	67.35	10.41	–	–
Hanley et al. (2013) – social scenes	14	14	67.58	10.33	78.62	9.71	–	–
Jones et al. (2008)	15	36	87	22.37	90.8	18.66	–	–
Kemner et al. (2007)	17	16	25.68	6	25.41	4.22	–	–
Kirchner et al. (2011)	20	21	–	–	–	–	–	7.05
Klin et al. (2009)	21	39	50.7	10.4	62.7	12.36	–	–
Klin et al. (2002)	15	15	90.4	9.21	96.3	5.71	–	–
Kuhn et al. (2010)	15	18	52.45	14.61	55.84	14.35	–	–
Marsh et al. (2015)	20	20	–	–	–	–	–	0.24
Nadig et al. (2010)	20	17	–	–	–	–	–	0.6
Norbury et al. (2009) – ALI vs. TD	14	18	74.8	11.52	78	8.81	–	–
Norbury et al. (2009) – ALN vs. TD	14	18	71.7	10.98	78	8.81	–	–
Parish-Morris et al. (2013)	60	50	36	–	38	–	0.37	–
Riby and Hancock (2008) – natural image; non-matched IQ	20	20	45.2	17.97	58.2	14.51	–	–
Riby and Hancock (2008) – natural image; matched IQ	20	20	45.2	17.97	60	9.78	–	–
Riby and Hancock (2009a)	22	22	13.62	2.2	27.24	17.16	–	–
Riby and Hancock (2009b) – cartoon image; matched IQ	20	20	59	17.61	64.2	16.31	–	–
Riby and Hancock (2009b) – cartoon image; non-matched IQ	20	20	59	17.61	71.4	11.26	–	–
Riby and Hancock (2009b) – cartoon movie; matched IQ	20	20	63	14.46	69.8	12.89	–	–
Riby and Hancock (2009b) – cartoon movie; non-matched IQ	20	20	63	14.46	73.4	12	–	–
Riby and Hancock (2009b) – natural movie; matched IQ	20	20	49.6	22.46	69.6	24.52	–	–
Riby & Hancock (2009b) – natural movie; non-matched IQ	20	20	49.6	22.46	73	17.93	–	–
Rice et al. (2012)	37	26	76	10.67	84.7	14.44	–	–
Sasson and Touchstone (2014)	15	15	46.6	10.17	49.85	10.17	–	–
Sasson et al. (2007)	10	10	65.03	10.59	76.43	8.2	–	–
Schwartzman et al. (2015)	11	17	18.8	9.3	44.5	30	–	–
Shi et al. (2015)	13	20	–	–	–	–	–	1.52
Shic et al. (2011)	28	34	70.2	7.02	83.3	11	–	–
Tenenbaum et al. (2014)	13	14	9.09	6.78	10.54	8.46	–	–
van der Geest et al. (2002)	16	14	–	–	–	–	0.54	–
Vivanti et al. (2014)	24	24	–	–	–	–	–	0.35
Wilson et al. (2010)	13	14	35.65	14.02	44.17	8	–	–

Table 4
Moderating factors of social attention.

	Model 0	Model 1	Model 2	Model 3	Model 4
Intercept	0.478 (0.06)***	0.326 (0.11)**	0.482 (0.10)***	0.251 (0.18)	0.246 (0.11)*
Age		0.014 (0.01)		0.012 (0.01)	0.008 (0.01)
NVIQ			0.129 (0.14)	0.071 (0.15)	0.102 (0.14)
VIQ			−0.179 (0.15)	−0.212 (0.14)	−0.202 (0.14)
Motion				0.097 (0.14)	
Social content				0.368 (0.14)**	0.396 (0.13)**
Ecological validity				−0.085 (0.16)	
AIC	75.4	74.3	77.6	71.5	68.05
BIC	79.4	80.2	85.5	87.26	79.87
Log likelihood	−35.7	−34.1	−34.8	−27.7	−28.03

* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

reduced in individuals with ASD when compared to TD individuals. As a test of publication bias, the effect sizes were plotted in a funnel plot that upon visual inspection showed no asymmetry, and therefore no indication that publication bias might be an issue. The trim-and-fill method (Duval & Tweedie, 2000) was also implemented, which estimated an additional 2 "missing studies" and adjusted the effect size to 0.50 with confidence limits from 0.33 to 0.68, very close to the initial value.

2.2. Moderating factors

The impact of the eight above-mentioned moderator variables on the difference in social attention between the two groups was also considered by analyzing the impact of age, non-verbal IQ matching, verbal IQ matching, motion, social content and ecological validity on social attention for all the identified experiments, and the impact of audio input and attention bids for the subset of experiments (30) that used as stimuli videos as opposed to still images (since still images by definition do not have a natural audio or attention bid component).

The analyses were conducted by using linear mixed effects models (see Table 4). Model 1 tested the influence of age on our dependent variable (the Cohen's *d* effect size), and showed that this predictor was not significant. Model 2 tested whether IQ matching influenced the effect size. The fixed effects in Model 2 included non-verbal IQ matching and verbal IQ matching, neither of which was significant. Model 3 tested whether motion, social content and ecological validity impacted the difference in social attention between the two groups while controlling for the impact of age, non verbal IQ matching and verbal IQ matching. Social content emerged as a significant predictor ($\beta = 0.368$, $p = 0.003$), while the other variables were not significant. This shows that the difference in social attention between the two groups increased with social content: the difference was larger when stimuli contained more than just one person. Model 3 was the best fitting model, log likelihood ration = −27.75 and explained 32.21% of the variance in effect sizes across studies. Thus, the final model, Model 4, shows the influence on social attention of social content (1 = more than one person) while controlling for age, non verbal IQ matching and verbal IQ matching.

To test the influence of audio input and attention bids on the difference in social attention between the ASD and TD groups, linear mixed effects models were used on a subset of the data, namely the experiments that had videos as stimuli. While controlling for the influence of age and verbal and non-verbal IQ matching, neither audio input nor attention bids impacted the difference in social attention in a significant way (audio input: $\beta = 0.092$, $p = 0.504$; social attention: $\beta = 0.217$, $p = 0.210$).

3. Discussion

This study examined research on social attention in ASD and typical controls focusing on eye-tracking studies, which compared attention to social as opposed to non-social stimuli. Two key results were found. First, participants with ASD have an overall diminished social attention. The average Cohen's *d* effect size across studies was 0.55, a medium effect. Second, of eight study characteristics only one predicted effect size: the number of people shown in the stimuli. This analysis can help to explain apparently contradictory results among published studies and highlights a key feature of experiments which seek to examine differences in social attention between ASD and neurotypical children.

These results show that ASD social attention impairment was higher when the social content of the stimuli was higher (i.e. the number of people exceeded one). As Birmingham, Bischof, and Kingstone (2008) have shown, for TD individuals, high social content increases attention to the eyes and faces. Our results suggest that this might not be the case for individuals with ASD. Moreover, Birmingham et al. (2008) have shown that high social content combined with high level of activity (several people interacting) further increased the attention to the eyes in TD individuals. Therefore, the comparatively low social attention in ASD in the context of high social content might be due to difficulty with monitoring higher number of people or difficulty with monitoring social interactions.

Additional insight into this difference comes from a study by Speer et al. (2007), which we were unable to include in this meta-analysis. These researchers tested participants on four types of stimuli: social dynamic, social static, isolated dynamic and isolated static. They found that social attention in the ASD group differed from the TD group for dynamic videos of social scenes but not for static photos of isolated individuals. They also found that gaze patterns in the exploration of social stimuli were atypical (which is beyond the scope of our meta-analysis) with decreased attention to the eyes and increased attention to the body, which predicted scores on a measure of social responsiveness.

An alternative interpretation is that reduced attention is related to the content of the stimuli but not necessarily to their social nature – for example, a busy dynamic scene without people could also lead to decreased attention in ASD. This is however unlikely since Pierce, Conant, Hazin, Stoner, and Desmond (2011) have used complex, dynamic geometric patterns as control stimuli and identified a subgroup of children with ASD preferentially attending to this non-social stimulus as compared to the social one (movies of dancing children). It would be valuable for future research to establish whether this effect holds with other dynamic and complex non-social control stimuli that are more often encountered outside the laboratory setting (for example movies of a busy highway). Also, Kemner et al. (2007) have shown that in static images complexity of a stimulus does not seem to reduce attention in ASD, on the contrary just like in TD individuals, it increases attention. Also, Riby et al. (2013) who used as stimuli photographs of cluttered rooms have not found an overall decreased attention to the scene in the ASD group.

This meta-analysis has shown that social content is a key factor for social attention in ASD and points to several important questions for future research. First, does social attention change proportionally to the increase in social content; that is, is there a threshold number of people in a scene at which ASD participants cease to pay attention? Due to lack of access to the stimuli only a very simple coding scheme was used in this meta-analysis: capturing whether the social stimulus contained one or more people and also considering stimuli with a mixed level of social content (when the authors collapsed their analysis across stimuli depicting one and more people) as high social content. Future studies will hopefully use more sensitive measures of social content. Second, what is the relationship between the number of people, the level of activity and the level of interaction as factors impacting social attention in ASD? The moderator variable in this meta-analysis is unable to make the distinction between the level of activity and the social content of the stimuli due to insufficient available data, so the two likely overlap. A study by Stagg, Linnell, and Heaton (2014), which showed interacting and non-interacting human figures, found that TD children spent a significantly longer time attending to the interacting figures than ASD children with language delays, but no differences were found between TD children and ASD children with normal language onset. The study used only static and schematic stimuli, so future research is needed in order to further investigate the effects of interaction in a rich social content scene on social attention in ASD.

The results of this meta-analysis also allow us to make some inferences regarding the factors that did not have a significant impact on social attention. Very importantly, the fact that age was not a significant moderator of social attention suggests that diminished social attention remains constant across development in individuals with ASD. However, caution is advised in interpreting this result, since many of the studies included in this meta- analysis, especially those reporting on adult data, average results across age ranges spanning over decades. Also, this meta-analysis can offer at best a cross-sectional view of the development of social attention. Longitudinal studies with careful in-depth analyses like the one conducted by Jones and Klin (2013) are better suited for mapping the changes in social attention across time. They found that children later diagnosed with ASD exhibit decline in eye-fixation already in the first 6 months of life. Future longitudinal research is crucial for determining whether this atypical trajectory continues in later years, whether it is restricted just to attention to eyes or it extends to social stimuli more broadly, and whether the decline ultimately plateaus or reverses with age. Another important theoretical consideration is the distinction between social attention behavior in early development and social attention behavior in later development, and the idea that they might not emerge from the same psychological processes. As Rice et al. (2012) point out, social attention deficits at different ages might mean different things from the point of view of the developmental trajectory of ASD: "the data from adults represent the cumulative effects of long-term atypical experiences, whereas the data from toddlers represent a time in which symptomatology profiles are still emerging" (p. 239).

The results of this meta-analysis also showed that IQ matching has no impact on the difference in social attention between the ASD and TD groups, in spite of concerns that directing one's attention to the socially relevant information in a scene might be linked to non-verbal IQ and not ASD symptoms per se. Studies who have included developmentally delayed individuals as control groups (e.g. Chawarska et al., 2012; Klin et al., 2009; Shic et al., 2011) support these results. They found significant differences in social attention between the ASD group and *both* the developmentally delayed group and the TD group. Similarly, matching on verbal IQ does not seem to eliminate group differences in social attention, further supporting the results obtained by Klin et al. (2002).

In terms of bottom-up stimuli characteristics, the results of this meta-analysis suggest that the difference in social attention between individuals with ASD and controls is not affected by motion processing. Given that social content was the factor with the highest impact on social attention, it is more likely that not any kind of motion processing is affected in individuals with ASD but more specifically motion resulting from activity associated with social interaction. In fact, a study by Pierce et al. (2011), mentioned above, has shown that toddlers with ASD have a preference for geometric moving patterns as opposed to moving children (doing yoga or dancing).

Ecological validity is another factor that did not significantly impact social attention. This suggests that diminished social attention in ASD might not be a result of difficulty with processing complexity. This is also supported by the results obtained by Kemner et al. (2007) who found no differences between the ASD group and the TD control group in terms of their attention to simple and complex figures. However, even if cartoons or schematic images may differ from photographs or videos, in that they are more realistic, it is still possible that even realistic representations do not induce the same social attention behavior as interactions with a real person. Research relies heavily on social representations rather than real people in studying social attention and thus might not capture social attention as it unfolds in day-to-day life. Two studies included in this meta-analysis studied social attention in live face-to-face interactions, and found no significant differences of the time spent looking to the partner (Falck-Ytter, Carlström, & Johansson, 2015) or to the partner's face (Nadig et al., 2010) between individuals with ASD and TD individuals. More studies using this live interaction paradigm, with careful manipulations of the interaction and stimuli involved are needed in order to gain a better understanding of how social representations as opposed to live interactions affect differences in social attention between ASD and TD individuals. This is especially important in the context of attention bids, which one would naturally expect to be more compelling coming from a real person rather than a video recording.

This meta-analysis also suggests that the presence of an audio track in conjunction with visual social stimuli does not impact social attention in ASD. This corroborates the finding that individuals with ASD show reduced multi-sensory facilitation (Collignon et al., 2013).

Attention bids also did not impact social attention significantly. However, this meta-analysis only included a relatively small number of experiments in which the social stimulus contained attention bids in the form of direct speech (nine experiments) with huge variations in the nature of this directed speech: from baby-directed speech (Chawarska et al., 2012) to a newsreader delivering news items straight to the camera (Bird et al., 2011). It is therefore possible that some types of attention bids and not others lead to greater differences in social attention between ASD and TD groups, that should be investigated in the context of more systematic experimental designs.

This meta-analysis investigated a fairly large number of factors that could potentially influence social attention in individuals with ASD. However, the list of factors is not comprehensive. Due to insufficient data reported in the studies, and due to the variety of measures used in eye-tracking studies, some factors could not be included.

One important factor left out was the salience of the non-social competing stimuli. Tager-Flusberg (2010) suggested that ASD might be driven by greater engagement in the world of objects rather than in the loss of motivation to engage in the social world. Some studies that could not be included in this meta-analysis due to differences in the measures used, have shown that social attention in ASD can be diminished when the competing non-social stimuli belong to the circumscribed interest category (e.g. trains) but not when the objects presented were unrelated to circumscribed interests (Sasson, Elison, Turner-Brown, Dichter, & Bodfish, 2011; Sasson & Touchstone, 2014; Sasson, Turner-Brown, Holtzclaw, Lam, & Bodfish, 2008).

Also, as mentioned above, Pierce et al. (2011) found that children with ASD prefer to attend to moving geometric patterns and that there might be ASD sub-phenotypes that are characterized by atypical attention to non-social stimuli. However, Chawarska, Macari, and Shic (2013) found that limited attention to the social stimulus in their study (i.e. the actress) was not accompanied by enhanced attention to objects, and both Chawarska et al. (2013) and Parish-Morris et al. (2013) have found that if the non-social stimulus is sufficiently salient (moving toys or videos of moving objects) both the ASD and the TD control groups pay more attention to the non-social stimulus than the social stimulus.

The studies included in this meta-analysis varied widely in the nature of the competing non-social stimuli presented. In some studies employing preferential looking tasks (Sasson & Touchstone, 2014) social and non-social stimuli were presented side by side and covered the same surface area. In some free viewing studies the scene was rich in non-social stimuli presenting a clutter of objects and furniture (Fletcher-Watson et al., 2009). At the other end of the salience spectrum, the non-social stimuli in other studies (Hanley et al., 2013) included just plain walls, and windows or doorframes. Further research is needed to properly quantify the impact of competing non-social stimuli salience on social attention in ASD by systematically varying the nature, size and complexity of the competing non-social stimuli.

Another moderating factor that could not be included due to lack of systematic reporting is symptom severity. Studies in this meta-analysis include population samples across the spectrum, from high-functioning ASD (i.e. Freeth et al., 2010; Nadig et al., 2010) to non-verbal or minimally verbal (Amso, Haas, Tenenbaum, Markant, & Sheinkopf, 2014). Previous studies have shown a link between ASD symptoms and social attention (Bird et al., 2011; Chawarska et al., 2012; Klin et al., 2002; Shic et al., 2011) and future research is needed to determine to what extent differences in social attention between ASD and TD individuals are moderated by symptom severity.

Another limitation of this meta-analysis is its use of a single measure of social attention (mean percentage of looking time). This measure has been selected because of its wide use and the consistency with which it is reported in the literature. However, other measures of social attention can offer more nuanced insights into the difference in social attention between ASD and TD groups. For example Wang et al. (2014) used initial orientation (did the participants look at social or non-social stimuli first in an array of both kinds of stimuli?) to determine the preference for attending to social vs. non-social elements of the scene as well as number of fixations to social stimuli (how many times did the participants' gaze visit social stimuli?) and the average length of a fixation to social stimuli (how long did they dwell on a social stimulus before saccading?). Sasson et al. (2008) used three measures of social attention: visual exploration (what was the number of social images viewed in an array of social and non-social stimuli?), perseveration (what was the average amount of time a social image was explored?) and detail orientation (what was the average number of fixations per social image explored?). Another measure used to investigate social attention is the latency to fixate social stimuli. Riby and Hancock (2009a) used this measure to determine whether social stimuli have the same saliency and pop-out effect for individuals with ASD as they do for TD individuals. These measures, combined with systematic manipulations of the stimuli can enhance our understanding of social attention in ASD and fill in the gaps left by the percentage of looking time measure. For example just by analyzing percentage of looking time to social stimuli, one cannot determine whether reduced looking time to the social stimulus is due to distraction coming from salient non-social stimuli, or rather because of failure to promptly detect the presence of the social stimuli. Adding measures of initial orientation as well as fixation/dwell time to analyses could elucidate that. Hopefully, future eye-tracking research will use and report consistently these alternative measures of social attention as well.

Finally, besides being reduced, social attention in ASD might also be atypical, which suggests that in addition to reduced motivation to attend to social stimuli, individuals with ASD also process these stimuli in atypical ways, for example by attending more to the mouth than the eyes (for a review see Guillon et al., 2014). Attention to some parts of social stimuli rather than others is beyond the scope of inquiry of this paper, which focused on the more basic issue of whether individuals with ASD attend less (and how much less) to social vs. non-social information. However, in order to obtain a full social attention profile of ASD, future research needs to investigate what parts of the social stimuli are informative for individuals with autism, and how rich and different the social information gathered from them is.

4. Conclusion

The present meta-analysis showed that individuals with ASD have overall reduced social attention as compared to typically developing controls, and that social attention in ASD is influenced by social content, which matches the conclusion reached by Guillon et al. (2014). The most important contribution of this meta-analysis is that it directs future research aimed at identifying differences between ASD and TD individuals toward studying social attention in the context of high social content situations by using and systematically varying stimuli depicting more people. By identifying the factor that significantly impacts social attention in ASD, the results of this meta-analysis make the first step toward informing theoretical models of ASD symptom-emergence, and together with further research can help inform interventions for ASD of the most favorable conditions for increased social attention in ASD: one-on-one interactions.

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