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Is it Avoidance or Hypoarousal? A systematic review of emotion recognition, eye-tracking, and psychophysiological studies in young adults with Autism Spectrum Conditions

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Abstract

A systematic review was conducted for studies exploring the link between gaze patterns, autonomic arousal and emotion recognition deficits (ERD) in young adults with Autism Spectrum Conditions (ASC) in the context of the eye-avoidance/hyperarousal and the orientation/hypoarousal hypotheses. These hypotheses suggest that ERD in ASC can be explained by either exacerbated physiological arousal to eye-contact interfering with emotion recognition, or blunted arousal not engaging the necessary attention and awareness mechanisms to process emotionally salient cues, respectively. Most studies have suggested that individuals with ASC display an overall reduced attention to the eyes, however, this was not always associated with ERD, and some studies also reported ERD with no evidence of atypical gaze patterns. The evidence from psychophysiological studies is also mixed. While some studies supported that individuals with ASC are hypoaroused during emotion processing, others reported hyperarousal or even partially supported both. Overall, these results suggest that the current autonomic arousal and gaze hypotheses cannot fully account for ERD in ASC. A new integrative model is proposed, suggesting a two-pathway mechanism, in which avoidance and orientation processes might independently lead to ERD in ASC. Current methodological limitations, the influence of alexithymia, and implications are discussed.

Keywords: autism; emotion; eye-tracking; arousal; two-pathway; model; alexithymia.

Highlights

- Arousal and gaze abnormalities have been associated with emotion recognition deficits (ERD) in Autism
- The evidence from psychophysiological and eye-tracking studies is mixed
- Autonomic arousal and gaze patterns cannot fully account for ERD in autism
- A two-pathway mechanism for gaze and arousal in autism model is proposed
- Arousal and gaze mechanisms might be modulated by Alexithymia

1. Introduction

Autism Spectrum Conditions (ASC) are mainly characterized by deficits in emotional reciprocity, socio-communication skills and restricted interests (American Psychiatric Association, 2013). Emotion Recognition Deficits (ERD) in particular have been extensively studied in individuals with ASC (see Harms, Martin, & Wallace, 2010; Lozier, Vanmeter, & Marsh, 2014; Uljarevic & Hamilton, 2013 for a review) and quoted as part of the core diagnostic aspects of the condition. These deficits are often reported to have the greatest impact on day-to-day social functioning, but the underlying neurobiological mechanisms remain poorly understood.

Prominent explanations for ERD in ASC have suggested atypical gaze as one of the possible underlying mechanisms. In fact, atypical gaze in children as early as 12 months of life has been found to be a valuable biomarker for predicting later severity of autism symptoms (Jones, Carr, & Klin, 2008; Papagiannopoulou, Chitty, Hermens, Hickie, & Lagopoulos, 2014). Two specific explanations linking abnormal gaze and ERD have been independently studied. Some have suggested that individuals with ASC display a reflexive ‘eye-avoidance’ in which they perceive the eyes to be threatening and over-arousing, thus interfering with emotion processing (Kliemann, Dziobek, Hatri, Baudewig, & Heekeren, 2012; Mathersul, McDonald, & Rushby, 2013a; Tanaka & Sung, 2016). Alternatively, others argue that individuals with ASC may display a ‘lack of orientation’ to the eyes due to a general hypoarousal state, not engaging the necessary physiological mechanisms to generate awareness and resonance to emotionally salient cues (Dalton et al., 2005; Schultz, Chawarska, & Volkmar, 2006).

These hypotheses are in line with the current views of emotion processing, consensually conceptualized as a psychophysiological goal-oriented process (Atkinson & Adolphs, 2011;

Calder & Young, 2005; Niedenthal & Brauer, 2012). It is also known that changes in physiological arousal (e.g. SCR) can index orienting responses to novel or significant environmental information, including socially-relevant stimuli (Sokolov, 1960; Barry, 1984; Mathersul, McDonald, & Rushby, 2013b). Furthermore, models of empathy have consistently suggested that the perception of emotion in others involves some level of physiological resonance that allows emotional contagion to occur.

Classical simulationist models such as the perception-action model (Preston & De Waal, 2002a,b; Preston, 2007) suggest that the perception of emotion automatically activates shared neural networks that represent the movements required to produce the observed action, which in turn activates somatic and autonomic responses. According to such accounts, this process instantiates automatic mirroring or re-creation of the observed emotional expression, facilitating understanding of the affective content in it (Blair, 2005; Decety & Moriguchi, 2007).

While these models generated a lot of interest surrounding putative notions on the mirror neuron system debate, some of the more modern and prominent models of empathy offer an alternative account for the mechanisms underlying empathy. These models detail the information processing elements that are necessary for empathy to occur (e.g. Bird & Viding, 2014; Coll et al., 2017). For instance, the SOME model proposed by Bird and Viding (2014) includes emotion identification as one important component of empathy, suggesting however that facial expressions are only one of the many inputs or routes that allow people to classify the affective state of another person. A prerequisite for empathy, however, is that of affect sharing, where the empathizer shares the affective experience of another. Bird and Viding’s model suggests that information inputs such as facial expressions trigger automatic associations learned through development, between emotional cues (e.g., facial expressions) and the representation of the affective state of another person and the corresponding affective states in the self. Importantly, this process is also thought to involve psychophysiological and somatic reverberances that validates the affective experience as veridical (Bird & Viding, 2014).

What the models just described have in common is the idea that failures in emotion identification and affect sharing may arise from attentional and motivational constraints as well as deficits in interoceptive and physiological signals. This gives plausibility to the gaze and arousal theories of ERD in ASC, as studies of neurotypical individuals have shown that different facial expressions have specific diagnostic features one should attend to, such as ‘eye’ for fear, and ‘mouth’ for happy (Ekman, 1999; Posamentier & Abdi, 2003; Scheller, Büchel, & Gamer, 2012). Furthermore, there is evidence suggesting that successful emotion recognition is partly influenced by the appropriate eye to mouth fixation ratios, which have to be adjusted accordingly for different emotions (Adolphs et al., 2005; Atkinson & Adolphs, 2011; Dadds et al., 2014). Validating the importance of eye and mouth cues and appropriate physiological responses for emotion processing, neuroanatomical studies have linked atypical processing of emotions to neural dysfunctions in the emotional circuitry, including but not limited to the amygdala, fusiform gyrus, insula and anterior cingulate cortex (Adolphs, Sears, & Piven, 2001; Atkinson & Adolphs, 2011; Bird et al., 2010; Craig, 2009; Critchley, Wiens, Rotshtein, Öhman, & Dolan, 2004; Dalton et al., 2005; Hadjikhani et al., 2004; Nacewicz et al., 2006).

The present systematic review aimed to analyze studies that tested gaze and arousal hypotheses for ERD in young adults with ASC, employing eye-tracking technology and/or psychophysiological measures of autonomic arousal. We also advance an initial attempt of an integrative model to explain gaze and psychophysiological arousal mechanisms underlying ERD in ASC.

It is important to point out that two recently published reviews have focused on a similar topic. One meta-analysis of gaze patterns during emotion recognition in children and adolescents has reported that atypical gaze patterns predicted social difficulties in groups with ASC (Papagiannopoulou et al., 2014). Likewise, Black et al. (2017) reviewed eye-tracking and electroencephalography (EEG) studies spanning from children to adult samples with ASC and reported altered visual attention to facial emotions and atypical activation of cortical areas associated with the processing of facially expressed emotions in ASC. It also highlighted that these deficits are more apparent in adult samples, which justifies the focus of the current review on adults.

However, neither of these reviews has focused specifically on emotion recognition deficits of adults with ASC, employing eye-tracking techniques combined with autonomic arousal measures. Additionally, prior reviews did not consider in detail both the avoidance and the orientation hypotheses with which the present review is primarily concerned, nor have attempted to put forward a model integrating the proposed mechanisms underlying the heterogeneity of emotion processing, gaze and arousal in ASC, which we seek to achieve in this paper. The purpose of our review was to shed light on the extent to which abnormalities in attention to the eyes and/or autonomic arousal may contribute to ERD in ASC.

2. Method

2.1. Study design

The present review was conducted in accordance with the PRISMA guidelines for systematic reviews and meta-analyses (Moher, Liberati, Tetzlaff, Altman, & Prisma Group, 2009). A literature search for articles published before October 2017 was conducted on PsycINFO, PsycArticles and the Elsevier Neuroscience and Psychology databases, using the following search terms: “autism spectrum disorders”, “autistic traits”, “emotion recognition”, “eye-tracking”, “arousal”, “hyperausal” “hypoarousal”, “skin conductance”, “electrodermal activity”, “facial expressions”, “affective response”, “eye avoidance”, “college students”, “community samples”, “undergraduate students”, “university sample”. All the searches were limited to include young adults.

2.2. Inclusion criteria

Studies measuring either eye-gaze patterns through eye-tracking techniques, assessing psychophysiological responses to emo-tional stimuli, or both, were included. For the psychophysiological studies, the initial goal was to find those studies that had assessed autonomic arousal responses, specifically electrodermal activity (i.e., skin conductance levels – SCL, skin conductance responses - SCRs) or heart rate (HR). However, only two studies met these criteria. Therefore, we decided to also include studies that analyzed arousal at the neural level (i.e., using Functional Magnetic Resonance Imaging - fMRI). In total, only 6 studies have examined emotion recognition deficits in ASC using eye-tracking and neurophysiological measures concurrently.

Fourtheen articles were excluded due to one or more of the following reasons: (a) did not use eye-tracking equipment to measure gaze or did not measure autonomic arousal (n = 4); (b) did not include adult samples (n = 3); (c) did not include a control group (n = 1); (d) only included avatar stimuli (n = 1); (e) only used non-emotional faces as stimuli (n = 4) and (f) only had a non-clinical sample (n = 1). Four additional studies identified from the references of the selected papers as well as from other reviews, were included. A total of 21 studies were included in this review. See Fig. 1 for a description of the selection process.

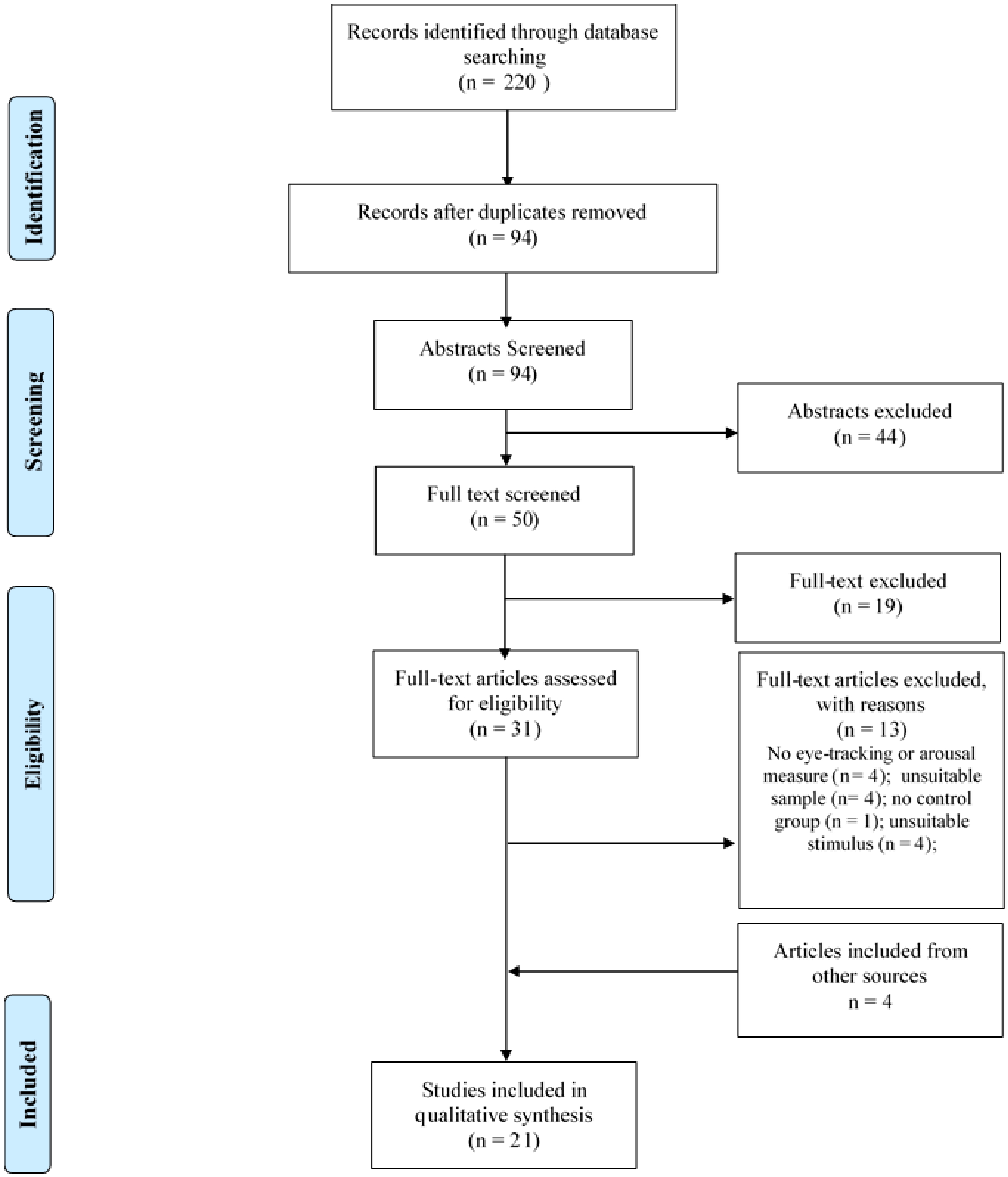

Figure 1. Flowchart of the literature review process

3. Results

Table 1 presents a summary of the studies included in the qualitative synthesis.

3.1. Study type

All studies were case-control where a clinical group (ASC) was compared to healthy controls.

3.2. Participant Characteristics

The analysis of the included studies revealed high heterogeneity regarding participant's characteristics. As detailed in Table 1 the clinical groups included mostly individuals diagnosed with Autism Spectrum Conditions, including High Functioning Autism (HFA) and Asperger's Syndrome. Most studies reported that individual in clinical samples had prior diagnosis of Autism in their clinical records, which were also independently confirmed with the DSM-IV criteria or using the respective clinical cut-offs on autism measures such as ADIR, ADOS and AQ as specified in Table 1. One study had a second clinical group with a diagnosis of schizophrenia in addition to the group with autism diagnosis (Sasson, Pinkham, Weittenhiller, Faso, & Simpson, 2016). While most clinical groups included in general individuals with autism who were high functioning and generally within a normal IQ range, one study included individuals characterized as Low Functioning Autism (LFA; Han, Tijus, Le Barillier, & Nadel, 2015). Participants age in both clinical and control groups ranged approximately from 17 to 48 years, with one exception where controls with a mean age of 13 years old were included to match the LFA group (Han et al., 2015).

3.3. Task design

Experimental tasks also varied. Most tasks consisted of explicit identification and labelling of emotions from images displayed on a computer screen, allowing the computation of

Table 1. A summary of the studies included in the qualitative synthesis.

Studies	Sample *N* (male) Mean age±*SD* ASC	NT	Stimuli	Autism Measures and materials	ROI	Main findings
Sasson et al. (2016)	21 (18) 23.43±4.36 *Schizophr*. 44 (27) 35.34±10.6	39 (23) 35.87±9.33	Pictures	DSM IV; Eye-tracking; fMRI	Face	ASC and Schizophrenia (SCZ) groups = accuracy to NT when faces were presented in isolation, but NT > clinical groups when faces were integrated into congruent and incongruent emotional scenes. Clinical groups also fixated on the face < NT in the incongruent condition.
Cassidy et al. (2015)	7 (15) 17.3±61.6	17 (6) 17.16±0.9	Pictures, video	AQ, DSM-IV Eye-tracking	Face	ASC group performance = NT on the static condition but had overall difficulty to infer negative states and had ↑ viewing times.
Grynszpan et al. (2015)	11(9) 21.36±4.41	11 (8) 31.82±5.65	Video	DSM IV; ADI-R, CARS. Eye-tracking	Face, rest of the image	ASC group failed to adjust visual scanning to contingent gaze condition, while NT adjusted.
Han et al. (2015)	LFA 12 (12) 19.5±3.1	TD child, 12 (12) 7.0 ±2.2, TD adolescent 12 (9) 13.4 ±0.9	Dynamic (morphing)	ADIR; CARS, eye-tracking	Human Face and Mechanical Face).	LFA group showed an intact perception of object change of state together with an ↓ perception of emotional facial change. For morphed robotic stimuli, LFA group displayed = duration of fixations to emotional regions and toward mechanical motion, while the NT individuals tracked the emotional regions only.
Cassidy et al. (2014)	36.44±12	30.4±13.49	Pictures, video	AQ, ADOS, DSM-IV Eye-tracking	Eyes/mouth	ASC accuracy < NT for retrodicting events involving recognition of genuine and feigned positive emotions, but there was no lack of attention to the eyes.
Mathersul et al. (2013)	*HFA* 28 (22) 22	31 (24) 22.	Videos	DSM-IV, EQ, SCR.	__	HFA = NT in their resting SCL. The ASC group with significantly ↓ resting SCL demonstrated ↓ recognition of basic emotions.
Zürcher et al. (2013)	22 (19) 27.6±7.7	22 (19) 23.7± 5.9	NimStim	DSM IV; ADOS, ADI-R, AQ; MRI Eye-tracking:	Eye, Mouth	No differences were observed in eye tracking results, fixation times and ratios eyes/mouth. However, ASC participants failed to show typical activation in the dorsal and ventral frontoparietal attention networks for averted *vs*. direct gaze.

Table 1. Continued

Studies	Sample size (male) Mean age±SD ASC	NT	Stimuli	Autism Measures and materials	ROI	Main findings
Kliemann et al. (2012)	16 (16), 30.44±6.34	17 (17); 30.47±6.23	Pictures	DSM-IV; AQ; ADI-R; ET fMRI	Eye, mouth	ASC participants showed ↑ eye movements away from the eyes, whereas NT ↑ gazed toward the eyes. ASC exhibited ↑ amygdala responses when initially fixating on the eyes, while NT showed ↑ response when initially fixating on the mouth.
Sawyer et al. (2012)	30 (18) 21.6±9.8	24 (7) 24.0±9.2	Pictures	DSM IV; eye- tracking	Face, eyes, mouth.	Individuals with Asperger's Syndrome were ↓ accurate at recognizing emotions and mental states but did not show evidence of gaze avoidance.
Falkmer et al. (2011)	24 (16) 29±10.8	24 (16) 28.9± 10.6	Static, Whole Face and Puzzled.	DSM-IV; ADIR Eye-tracking	Eye, mouth, whole face, other parts	ASC had ↓ fixations on the eyes and ↑ on the mouth compared to NT on puzzled stimuli. ASC ↓ fixation time on the mouth, ↓ fixations on eyes and ↑ on other parts of face; ASC ↑ fixation on non-core/other parts of the face than NT. ↑ accuracy in ASC was associated with ↑ fixations on the eyes of puzzled stimuli, ↓ fixations on non-core/outside regions of whole face stimuli, and ↓ fixation times on the eyes of puzzled stimuli and ↓ fixation times to the mouth of whole faces.
Kirchner et al. (2011)	20 (15) 31.9 ± 7.6	21 (15); 31.8±7.4	Pictures	DSM IV, ADIR, eye tracking.	Whole picture, face, eyes, mouth,	ASC group showed ↓ face processing. There was no significant difference between the groups for the eye-ROI but ASC group showed ↓ fixation time on the face-ROI compared to NT.
Kliemann et al. (2010)	12 (12) 22-48	19 (14) 21-42	Pictures	DSM_IV, ADI-R; ASCI Eye-tracking	Eye, mouth	ASC showed an overall ↓ preference for the eye region and ↑ fixation changes away from the eyes. ↑ fixation on the eyes (but not mouth) is associated with ↑ recognition.
Hernandez et al. (2009)	11 (11) 24.09±8.31	22 (22) 22.7±3.4	Pictures/ avatar	DSM IV Eye-tracking	eye, nose, mouth	ASC group looked significantly ↓ to the eyes and did not show a preference for the mouth region compared to NT. Healthy subjects strategically began face exploration on the eyes.

Table 1. Continued.

Studies	Sample size (male) Mean age±SD ASC	NT	Stimuli	Autism Measures and materials	ROI (measure)	Main findings
Hubert et al. (2009)	16 (14) 25±9	16 (14) 27±10	Videos	DSM-IV; ASSQ, SCR	___	ASC = NT on behavioural performance. ASC group did not show SCR variations when they were engaged in ER task while NT did.
Boraston et al. (2008)	18 (15) 35.4±12.3	18 (15) 36.7±14.0	Pictures	ADOS, Eye Tracking	Eye, Mouth	ASC group showed ↓ discrimination of posed vs. genuine expressions and displayed ↓ gaze times and fixations to the eyes compared to NT. Mouth fixation is heterogeneous among ASC.
Corden et al., (2008)	31 (16) 33.8±13.60	32 (16) 16 ±11.58	Ekman–Friesen pictures	AQ; ADOS; Eye-tracking	Eye, Mouth	ASC group had ↓ recognition of fearful and sad faces and spent significantly ↓ time fixating on the eye region for all faces compared to NT
Rutherford et al. (2008)	11 (11) 25.8±6.09	11 (11) 25.7 ± 8.87	Pictures Baron-Cohen.	ADOS; Eye-tracking	Eye, Mouth	ASC = NT on accuracy, reaction time, and fixation duration. Although ASC individuals looked ↓ at the eyes in complex emotions, their accuracy was close to NT.
Spezio et al. (2007a)	9 (9); 23±6.75	10 (10); 28±8.15)	Ekman faces	DSM-IV ICD-10; Eye-Tracking	*Bubbles*: eye, mouth *Eye-tracking*: eye, mouth	HFA ≠ from NT in the features they relied upon the most while making emotion judgments. The HFA group showed ↓ use of information from the eye regions and a marked reliance in the mouth, compared to NT. However, there were no ≠ in accuracy or fixation durations.
Spezio et al. (2007b)	8 (8) 23± 7.11	10 (10) 28± 8.15	Ekman faces	DSM-IV/ ICD-10; Eye-Tracking	*Bubbles*: eye, Mouth *Eye-tracking*: Eye, nose, Mouth, Face, Eyebrow	ASC > TD fixation time on mouth when bubbles revealed ↑ information in the left eye. ASD < fixation time on mouth < NT when bubbles revealed ↑ information at the mouth
Neumann et al. (2006)	10 (10) 23 (2)	10 (10) 28 (3)	Pictures/ bubbles	DSM-IV/ICD-10, ADI; ADOS eye-tracking	Whole face, eye, mouth	ASC did not differ from NT in viewing of upright whole faces. But ASC fixated ↑ on the mouth and ↓to the eyes of both inverted and bubbled faces compared to NT.

Table 1. Continued

Studies	Sample size (male) Mean age±SD ASC	NT	Stimuli	Autism Measures and materials	ROI (measure)	Main findings
Dalton et al. (2005)	*Study1* 14 (14); 15.9±4.71; *Study 2* 16 (16); 14.5± 4.60	*Study 1* 12 (12); 17.1±2.78; *Study 2* 16 (16) 14.5±4.56	Pictures KDEF	DSM-IV Eye-Tracking, fMRI	Eye, mouth	ASC group had ↓fixation time on the eyes compared to NT. In the ASC group (but not the NT), activation in the fusiform gyrus and amygdala correlated positively with the time spent fixating on the eyes.

Notes:

ADI-R –The Autism Diagnostic Interview-Revised; CARS - Childhood Autism Rating Scale; ADOS - The Autism Diagnostic Observation Schedule; AQ – Autism Quotient; ASCI - Asperger Syndrome (and High-Functioning Autism) Diagnostic Interview; DSM IV - Diagnostic and Statistical Manual of Mental Disorders; ICD 10 – International Classification of Diseases 10; ASC – Autism Spectrum Conditions; EQ - Empathy Quotient Questionnaire; LFA/HFA - Low/High Functioning Autism; RMET - 'Reading the Mind from the Eyes'' task or Eyes Test. ↑ (increased, more) ↓ (decreased or less).

accuracy scores. While most of the studies used static images of facial expressions as stimuli, six studies employed dynamic stimuli (Cassidy, Ropar, Mitchell, & Chapman, 2014; Grynszpan & Nadel, 2015; Han et al., 2015; Hubert, Wicker, Monfardini, & Deruelle, 2009; Mathersul et al., 2013a). The majority of the experimental designs displayed the faces in full but two studies manipulated stimuli to display only portions of the face either through puzzles (Falkmer, Bjällmark, Larsson, & Falkmer, 2011) or bubbles (Neumann, Spezio, Piven, & Adolphs, 2006; Spezio, Adolphs, Hurley, & Piven, 2007b) and one study manipulated the presentation of congruent vs. incongruent contextual information with the facial stimuli (Sasson et al., 2016).

3.4. *Eye Gaze Patterns and Emotion Recognition in ASC*

From the 16 studies that employed eye-tracking techniques, 11 reported significant differences in gaze patterns between ASC and neurotypical (NT) individuals. Increased avoidance of eye contact was observed in ASC adults, suggested by an overall reduced preference for the eye region and increased fixation changes away from the eyes (Boraston, Corden, Miles, Skuse, & Blakemore, 2008; Corden, Chilvers, & Skuse, 2008; Dalton et al., 2005; Grynszpan & Nadel, 2015; Kirchner, Hatri, Heekeren, & Dziobek, 2011; Kliemann, Dziobek, Hatri, Steimke, & Heekeren, 2010, 2012; Sasson et al., 2016). Meanwhile, this eye avoidance does not necessarily suggest an increased preference for mouth compared to the eyes: increased mouth fixations are not associated with better emotion recognition, while eye fixations are (Kliemann et al., 2010).

Some studies suggested that fixation time on the eyes appears to be the strongest positive predictor of emotion recognition accuracy, with the ASC group performing poorly on standard emotion identification tasks as well as puzzle designs (Boraston et al., 2008; Corden et al., 2008; Falkmer et al., 2011; Kliemann et al., 2010). However, no group differences were found when using a more naturalistic task designed to have social saliency (Falkmer et al., 2011; Kirchner et al., 2011).

At least three studies suggested that compared to controls, ASC adults were impaired in their recognition of negative emotions, especially fearful and sad expressions (Corden et al., 2008; Cassidy et al., 2014; Cassidy, Mitchell, Chapman, & Ropar, 2015). Most importantly, the failure to fixate on the eyes predicted the degree of impairment in recognizing fearful and neutral expressions. The authors argued that negative emotions are generally more challenging and that spontaneous and neutral expressions are mixed and also hard to interpret.

While the studies above demonstrated deficits in recognizing negative emotions, Boraston et al. (2008) showed for the first time that compared to matched controls, adults with ASC are less capable of discriminating posed from genuine positive expressions. Eye-tracking results also revealed that ASC group displayed different gaze patterns, with shorter gaze times and fewer fixations to the eyes, compared to controls. Furthermore, there was a negative correlation between the ability to discriminate genuineness and social interaction impairment, which highlights the effects of these deficits for day-to-day functioning.

Other eye-tracking studies reported a more general rather than emotion-specific gaze problems on standard emotion recognition tasks (Dalton et al., 2005; Hernandez et al., 2009; Kliemann et al., 2010; Neumann et al., 2006). A study by Sasson et al. (2016) compared individuals with schizophrenia, ASC, and neurotypical individuals highlighted the importance of contextual information. They reported that unlike neurotypical individuals, both clinical groups failed to increase prioritization of facial information when surrounding contextual cues were ambiguous. A similar effect was found when faces were presented in puzzles (Falkmer et al., 2011). However, Sasson et al. (2016) found no deficits when emotions were presented in isolation. On another account, two studies suggested that the ERD in ASC was related to an abnormal top-down strategy to allocate visual attention (Neumann et al., 2006) as well as deficits in processing motion related cues to emotions, rather than over-sensitivity to facial cues (Han et al., 2015).

About one-third of the eye-tracking studies paint a confusing picture regarding the role of eye and mouth fixations, either opposing the findings of atypical gaze patterns, or suggesting that when atypical gaze is present, it is not the primary cause for ERD. Interestingly, two studies that used the gaussian bubbles technique, where parts of the facial image were randomly revealed through image bubbles, showed that individuals with high functioning autism (HFA) were different from controls in the features they relied upon to make emotion judgments (Spezio et al., 2007a,b). The HFA group had a decreased use of information from the eye regions and a marked reliance on information from the mouth region. Surprisingly, no differences in accuracy or fixation durations were observed. The authors suggest that it is possible that the social skills training that individuals with ASC typically go through might explain this apparent contradiction, since participants in the HFA group had previously participated in studies requiring emotion recognition judgments and had received extensive, long-term training in social gaze and emotion judgment.

Similarly, no differences were observed in fixation time ratios to eyes and mouth in a study looking at the effect of averted gaze (gazing away) versus overt gaze (direct gaze) of fear expressions (Zürcher et al., 2013). Rutherford and Towns (2008) also found no significant group differences in accuracy for simple vs. complex emotional expressions, nor reaction and fixation times. Even though individuals with ASC looked relatively less at the eyes for complex emotions, their accuracy was close to controls on both conditions. This suggests possible use of compensatory strategies that seem to help processing emotions in ASC (Spezio et al., 2007a,b). In contrast, two studies reported that individuals with ASC performed worse on emotion recognition tasks compared to controls but there was no evidence of eye-avoidance, adding that gaze patterns cannot entirely explain ERD in these individuals (Kirchner et al., 2011; Sawyer, Williamson, & Young, 2012).

In summary, about two-thirds of the eye-tracking studies report some level of atypical gaze patterns in ASC (Boraston et al., 2008; Corden et al., 2008; Dalton et al., 2005; Falkmer et al., 2011; Grynszpan & Nadel, 2015; Kliemann et al., 2010, 2012; Sasson et al., 2016). Even though individuals with ASC seem to maintain a similar pattern of interest in the eyes to controls, they tend to spend less time on them (Hernandez et al., 2009).

3.5. Physiological Arousal on Emotion Recognition in ASC

A total of six studies examined the relationship between physiological arousal and emotion recognition in adults with ASC, and evidence for both hypoarousal and hyperarousal has been reported. An fMRI study showed that, compared to controls, adults with ASC had reduced activation in the dorsal and ventral frontoparietal attention networks in response to averted gaze and increased responses to direct gaze, for fear expressions (Zürcher et al., 2013). Nonetheless, no group differences were observed for fixation times to eyes and mouth.

A study focusing on electrodermal reactivity reported that despite similar behavioral performances on emotion recognition tasks, unlike controls, adults with ASC had a lower SCR which did not display variations when engaged in a task of explicit identification of emotional facial expressions (Hubert et al., 2009). These findings suggest that ASC individuals are characterized by hypoarousal, supporting the hypothesis of deficits in physiological resonance. However, contrary to the argument of the orientation hypothesis, no evidence of lack of orientation to the eyes was found. Another study assessing arousal through electrodermal activity, revealed that although the autism and neurotypical groups did not differ significantly in their resting arousal levels, the ASC group with blunted resting SCL was impaired in recognition of basic emotions (Mathersul et al., 2013a). On the other hand, the group of individuals with autism that had typical arousal did not differ from neurotypicals on emotion recognition abilities. These studies suggest that sub-optimal arousal levels impair social cognition abilities.

There is also evidence of reversed group patterns of arousal in response to eyes and mouth fixations. While adults with ASC exhibited relatively greater amygdala responses when initially fixating on the eyes, controls displayed a relative increase in the same region when initially fixating on the mouth (Dalton et al., 2005; Kliemann et al., 2012). The authors also argued for the integration of the avoidance and orientation hypotheses, proposing that both components may coexist, yet to varying intra and interindividual degrees in ASC. They propose that arousal is modulated by the time spent fixating on the eyes, while reduced fixations to the eyes are generally associated with lower arousal, increasing fixation to the eyes is associated with increased arousal.

Using a self-report measure of social anxiety, Corden et al. (2008) found that poor fear recognition and reduced fixation on the eyes were also independently associated with greater levels of social anxiety in individuals with ASC. This provided behavioral evidence supporting the hyperarousal hypothesis. However, fixation to the eyes was not correlated with the severity of autism symptoms and this study did not measure physiological arousal per se. Instead, it used a self-report measure of social anxiety as an indicator of arousal tendencies.

4. Discussion

The eye-tracking results for ASC and emotion processing are very heterogeneous. This is particularly surprising considering that atypical eye-gaze has been treated as a hallmark of the social communication deficits in the ASC literature. Nonetheless, the majority of the studies have suggested that individuals with ASC show some level of active or reflexive avoidance to the eyes, missing subtle socially relevant cues conveyed by this region (Corden et al., 2008; Dalton et al., 2005; Falkmer et al., 2011; Kliemann et al., 2010, 2012). These cues are important for processing emotional expressions, particularly negative emotions like fear and sadness which engage the eye region in a prominent way (Ekman, 1999; Posamentier & Abdi, 2003; Scheller et al., 2012). Furthermore, healthy adults seem to strategically start face exploration on the eyes, something that individuals with ASC fail to do (Hernandez et al., 2009).

Yet, some studies did not find atypical gaze or ERD at all in relation to ASC (Kirchner et al., 2011; Rutherford & Towns, 2008; Sawyer et al., 2012; Zürcher et al., 2013); or reported that atypical gaze had no impact on emotion processing deficits (Spezio et al., 2007a,b). However, some of these studies are likely to be underpowered (e.g. Rutherford & Towns, 2008; Spezio et al., 2007a,b).

Conflicting findings can also stem from significant methodological heterogeneity including stimulus type and intensity, the number of emotions studied, and sample characteristics. For example, while Kirchner et al. (2011) replicated ERD in ASC adults using standard emotion recognition tasks, no difference emerged when they used more naturalistic stimuli in which emotions were integrated into context. However, Sasson et al. (2016) reported that while ASC did not differ from controls on isolated standard emotion recognition tasks, they did not benefit from integration of contextual cues as much as controls. This paints a conflicting picture regarding the role of contextual information, as it is not entirely clear the extent to which individuals with ASC benefit from contextual information during emotion recognition.

It should be noted that some studies looked at a limited range of emotions (one or two; e.g., Boraston et al., 2008; Zürcher et al., 2013). Even in the studies that successfully integrated the whole range of basic emotions, some only found differences in accuracy in the complex emotions conditions (Rutherford & Towns, 2008). Regardless, this begs the question whether gaze patterns can fully account for emotion recognition abilities in individuals with ASC.

Additionally, it is desirable to integrate more ecologically valid stimuli as opposed to the standard emotion recognition tasks that traditionally use prototypical displays of emotional expressions, usually high in intensity. Such tasks may fail to capture subtle differences in performance (Cassidy et al., 2015; Baron-Cohen, Wheelwright, Hill, Raste, & Plumb, 2001; Golan, Baron-Cohen, Hill, & Golan, 2006; Pelphrey, Morris, McCarthy, & Labar, 2007; Sarkheil, Goebel, Schneider, & Mathiak, 2013). Alternatively, the use of dynamic stimuli may provide a more sensitive measure to test attention and arousal processes related to emotion processing in clinical populations (Richoz, Jack, Garrod, Schyns, & Caldara, 2015; Trautman et al., 2009; Sasson et al., 2016). However, some suggest that adults with ASC have problems integrating dynamic facial features and that dynamic fearful gaze stimuli did not enhance attention orienting in individuals with ASC (Shah, Bird, & Cook, 2016; Uono, Sato, & Toichi, 2009). Again, this also paints a conflicting picture regarding the role of dynamic information for this group. Nonetheless, dynamic datasets and inclusion of context in emotion recognition experiments are preferred, as it mimics more closely real-world situations (Krumhuber, Kappas, & Manstead, 2013; Smith, Montagne, Perrett, Gill, & Gallagher, 2010).

One aspect that was often neglected and not discussed in these studies is that stimulus intensity can affect the relative importance attributed to different parts of the face by the perceiver, and thus face exploration patterns. For instance, specific face regions (i.e., mouth, eye) have been shown to be more diagnostic or informative for subtle as opposed to extreme facial expressions (Cassidy et al., 2015; Golan et al., 2006; Hernandez et al., 2009; Pelphrey et al., 2007; Philip, Whalley, Stanfield, Sprenglemeyer, & Santos, 2010; Smith et al., 2010). Validating the importance to account for stimuli intensity, a recent study that varied stimuli intensity reported diminished sensitivity in emotion processing for low to medium but not high emotional expressions in ASC (Wingenbach, Ashwin, & Brosnan, 2017).

Moreover, eye and mouth cues on emotion expressions may be visible peripherally even when subjects are not fixating at those cues (see Bayle, Schoendorff, Hénaff, & Krolak-Salmon, 2011 for emotional processing through peripheral vision). This might mitigate the importance of having to attend directly to specific face regions when processing emotions. This can be problematic in eye-tracking experiments because it can distort the meaning of some of the eye-tracking variables. For instance, it seems intuitive that if eye vs. mouth cues can be detected peripherally in high intensity facial expressions, fixation to one region of interest in the face, e.g. mouth, does not necessarily preclude the cues from the other competing region of interest from being processed simultaneously, without the need to reorient gaze. Therefore, any conclusions regarding the effect of gaze on emotion recognition, derived from observations of increased or decreased gaze to either eyes or mouth cues need to be treated with caution.

It is also important to note that some studies were statistically underpowered with very small samples (e.g., Spezio et al., 2007a, b; Neumann et al., 2006). With few exceptions, this was mainly due to technical problems with the eye-tracking acquisition, forcing the exclusion of participants and limiting the opportunity for more complex analyses. This might also have influenced statistical manipulation decisions that may have artificially inflated power in these studies (e.g., Kliemann et al., 2012).

Some studies also did not control for possible confounds such as the effect of medication in clinical samples (Dadds et al., 2014; Feeser et al., 2015) and previous interventions (Southall & Campbell, 2015; Spezio et al., 2007a,b). Most notably, studies generally failed to control for comorbid alexithymia that is reported to have high rate of incidence in ASC (see Bird & Cook, 2013; Cook, Brewer, Shah, & Bird, 2013). Some authors have persuasively argued for the ‘alexithymia hypothesis’, suggesting that comorbid alexithymia is the factor underlying ERD in ASC, and not autism per se (see Bird & Cook, 2013; Cook et al., 2013; Brewer, Happé, Cook, & Bird, 2015; Gaigg, Cornell, & Bird, 2018; Oakley, Brewer, Bird, & Catmur, 2016).

It would be ideal to have more studies assessing gaze patterns and psychophysiological measures simultaneously with free and contingent gaze conditions. However, at present, very few studies combined such techniques to study ERD in young adults with ASC. Of the six studies that measured arousal, three supported the hypoarousal hypothesis (eg. Mathersul et al., 2013a; Hubert et al., 2009; Zürcher et al., 2013), while the other three suggested that hyperarousal effect was also present and that these processes need not be mutually exclusive; in fact, arousal might be modulated by gaze fixation to the eyes (Dalton et al., 2005; Kliemann et al., 2012; Mathersul et al., 2013a; Sasson et al., 2016).

4.1. A two-pathway model

The inconsistent results reported in this review suggest that arousal and fixations cannot fully account of emotion recognition problems in ASC, at least not based on the separate accounts for

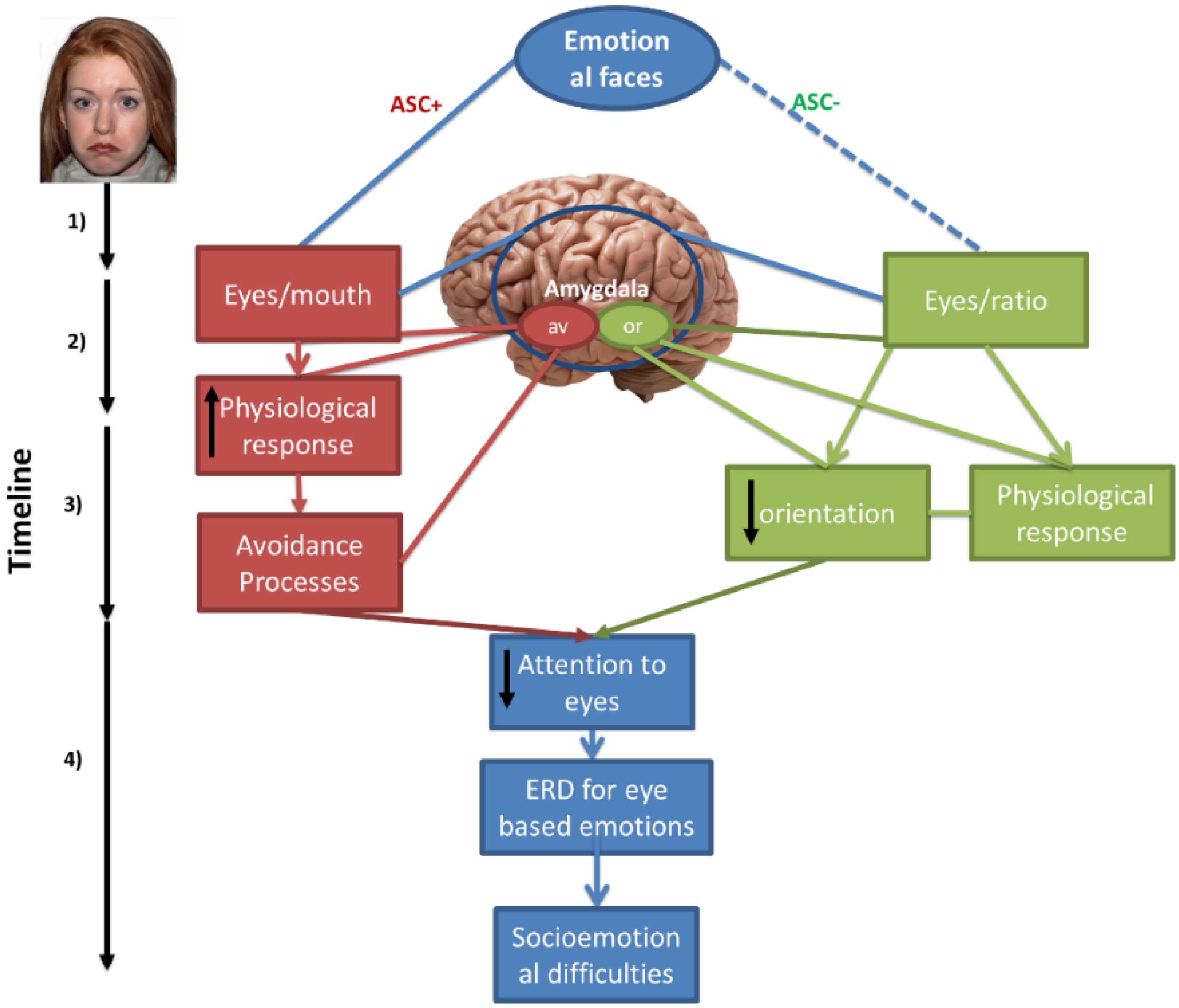

Figure 2. Two pathway Integrative avoidance-orientation model to explain ERD in ASC (ASC-) Hypoaroused (lack of orientation - or) green pathway in the right vs. (ASC+) hyperaroused (avoidance - av) red pathway in the left, are controlled by different amygdala subnuclei.

1. Baseline arousal in ASC influence orientation to socially relevant cues (e.g. eyes). After a stimulus (facial expression) presented ASC- will show a delay to approach the eyes (represented by dashed lines in the right) compared to the ASC+;
2. Attention to eyes (fixation, saccades) results in an increase in the physiological responses.
3. Increase in physiological responses triggers avoidance processes to reduce aversiveness in the ASC+. The ASC- group is less sensitive to the meaning of the eyes and reduces orientation to the eyes.
4. Reduced attention to the eyes results in deficits processing emotions that convey diagnostic features in the eye region or that have conjoint diagnostic features in the eyes and mouth. (e.g. sad, fear, genuine happiness). Face stimulus from NimStim (Tottenham et al., 2009).

the avoidance and the orientation hypotheses. Nonetheless, prior research has largely ignored the possibility that avoidance and orientation processes need not be mutually exclusive. Both subgroups, characterized by hypoarousal and hyperarousal, are conceivable within the very heterogeneous autistic phenotype. For instance, the amygdala, a region that has been robustly implicated in emotion processing and reflexive emotion mechanisms, and believed to be impaired in ASC, contains diverse structural and functional subnuclei (Adolphs, Baron-Cohen, & Tranel, 2002; Lutchmaya, Baron-Cohen, & Raggatt, 2002; Atkinson & Adolphs, 2011). Therefore, avoidance and orientation processes that are believed to be partially controlled by the amygdala may be regulated by different subnuclei (Dalton et al., 2005; Hubert et al., 2009; Kliemann et al., 2012; Zürcher et al., 2013). This can also extend to other areas such as the fusiform gyrus, insula, anterior cingulate cortex, dorsolateral prefrontal region and ventromedial frontal region which have been implicated in either emotion recognition problems (Adolphs et al., 2001; Atkinson & Adolphs, 2011; Sabatinelli et al., 2011) atypical modulation of arousal responses (Bird et al., 2010; Raine, Reynolds, & Sheard, 1991; Tranel & Damasio, 1994), modulation of attention to emotional stimuli (Adolphs et al., 2001; Adolphs, Baron-Cohen, & Tranel, 2002; Adolphs et al., 2005) or all of the above.

Accounting for this possibility, we propose a new integrative model of the avoidance and the orientation hypotheses, suggesting a two-pathway mechanism through which physiological arousal and gaze patterns may affect emotion processing in ASC (see Fig. 2). To describe this model, one should accept that the heterogeneity of the autism phenotype can produce different arousal profiles which may form different clusters with relatively independent mechanistic pathways to ERD, that is, hyperarousal (ASC+) vs. hypoarousal (ASC-) subgroups.

Under our model, arousal is expected to influence early orientation to or awareness of emotionally salient cues (e.g. eyes) after a facial expression is presented. Attention to eyes, however, is expected to increase the absolute physiological responses for both subgroups. Above a certain threshold this increase in arousal triggers avoidance processes in the ASC + group to reduce aversiveness. In contrast, the increase in arousal in the ASC- group will likely be minor or absent, and the ASC- is less sensitive to the meaning of the eyes, either not orientating too much attention to it, or simply not engaging with these cues in a meaningful way. Both pathways, in theory, can ultimately result in emotion processing deficits that are probably emotion-specific rather than general, affecting especially the recognition of eye-related emotions (e.g., fear and sadness). Under this model, the heterogeneity in emotion recognition performance in ASC can be explained by the relative position of each individual along the two orthogonal dimensions, the arousal (hypoarousal-hyperarousal) and avoidance-orientaion dimensions such that only individuals falling at the extremities, and are part of the hyperarousal-avoidance and the hypoarousal/low-orientation clusters will likely display ERD (see Fig. 3).

Most individuals with ASC that have typical or close to typical arousal are expected to perform similar or close to non-clinical individuals, or will exhibit much more subtle deficits in emotion processing.

This model is consistent with recent evidence supporting the alexithymia hypothesis and recognizes the heterogeneity of the autism phenotype. Alexithymia is a subclinical condition characterized by a reduced ability to identify and describe one’s own emotion, reduced empathy and deficits in recognizing the emotions of others (Bird & Cook, 2013). Atypical psychophysiological mechanisms (Gaigg et al., 2018; Shah et al., 2016) and atypical gaze ratios

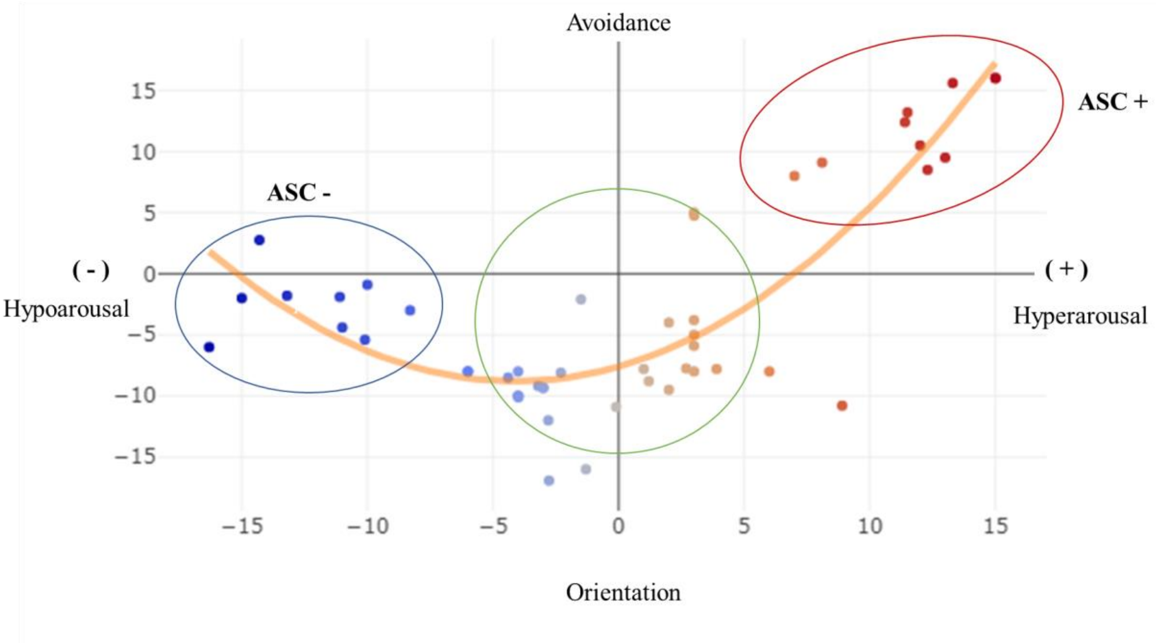

Fig. 3. Hypothetical illustration of the distribution of individuals with ASC along the hypoarousal-hyperarousal (x-axis) and the avoidance-orientation (y-axis) dimensions according to the two-pathway model. While most non-clinical individuals as well as some individuals with ASC who do not show ERD are likely to be characterized by optimal levels of arousal and orientation to emotionally salient stimuli (middle cluster), the two ASC groups clustered at the extremities are more likely to show ERD. The ASC- in the left is characterized by hypoarousal and reduced orientation to emotionally salient-cues and the ASC+ on the right is characterized by hyperarousal and avoidance tendencies. These deficits will likely vary in intensity, based on the individuals relative deviation from the optimal arousal and orientation areas.

(Bird, Press, & Richardson, 2011) have been reported to be associated with alexithymia during emotion processing tasks. It is possible that the gaze and arousal mechanisms underlying ERD in ASC are in fact modulated by alexithymia through interoceptive deficits (see Bird & Cook, 2013). In fact, the possibility of the existence of alexithymia subtypes: Type I associated with reduced physiological arousal, and Type II with typical physiological arousal but disconnected from higher cognition (Bermond et al., 2007; Bird & Cook, 2013) is consistent with the two-pathway avoidance-orientation model proposed here. This would also explain why the physiological arousal findings in ASC are highly mixed and hard to consolidate. Nonetheless it is important to clarify if the physiological arousal abnormalities are linked to autism, alexithymia, or their comorbidity, as well as if they are a cause or consequence of emotion processing deficits.

Additionally, this model offers operational hypotheses that are easily testable for each pathway, pointing for instance that (1) reduced fixation to the eyes and more saccades changes away from the eyes, after the first fixation, may be associated with an avoidant, hyperactive profile, and (2) delayed orientation to the eyes measured by entry-times and reduced physiological arousal would better describe a lack of orientation associated with a hypoarousal state.

This model is also consistent with some of the prominent models of empathy discussed earlier, as they suggest that arousal responses might modulate affect sharing and that attentional and motivational resources might interfere with emotion identification that is also important for affect sharing (see Bird & Viding, 2014 for a complete discussion). It is important to acknowledge that as explained by Bird and Viding's model, there are other routes that can influence affect cue classification, including situational in-formation, social scripts and theory of mind. Although the two-pathway model is compatible with those accounts, we chose to focus here specifically on facial expressions as the information input to emotion identification and affect sharing, which might be disrupted by deficits in motivation, attention, or physiological resonance.

If supported, this model may help clarify the neurophysiological mechanisms underlying the heterogeneity of emotion processing skills in ASC and explain why previous research has produced a considerable amount of mixed findings. Clarifying these mechanisms is essential to develop cost-effective and better-tailored interventions to remediate social deficits in ASC.

For example, this model suggests that cueing interventions focusing on increasing attention on the eyes may be contraindicated or less beneficial to avoidant individuals, while interventions that aim to regulate physiological arousal induced by eye-contact may prove to be more fruitful. Similarly, interventions focusing on cueing attention to the eyes using a more cognitive psychoeducational approach which emphasizes the meaning and structure of emotional cues, as well as interventions aiming to raise the physiological arousal responses up to optimal levels, may be more useful for hypoaroused individuals who lack instinctive orienting responses to the eyes.

5. Conclusions

The present article aimed to provide a systematic and comprehensive review of eye-tracking and physiological studies that assessed emotion recognition in adults with ASC, testing the eye avoidance and the orientation hypotheses. Although there is some support for atypical gaze and arousal in ASC adults, overall results are highly inconsistent. This might suggest that arousal and fixations as conceptualized by the avoidance and the orientation hypotheses cannot fully account for ERD in ASC.

We have put forward an initial integrative model outlining a two-pathway mechanism in which physiological arousal and attention to the eyes may underlie ERD in ASC. This model is compatible with the alexithymia hypothesis, recognizes the heterogeneity of the autism phenotype, and is consistent with contemporary empathy models. If supported, the two-pathway model may help explain the disparity of findings based on the traditional accounts of the orientation and avoidance hypotheses, and contributes to the conceptualization of new evidence-based and better-tailored interventions.

It is important to acknowledge that although we propose a new model to explain gaze and physiological arousal during emotion processing in ASC, this is far from a conclusive product, and intends to be suggestive rather than prescriptive. We hope that the model will be useful in directing attention to how gaze and arousal may help elucidate the mechanisms underlying the current heterogeneous reports of emotion recognition abilities in autism. Future studies would benefit from addressing methodological issues, including using more dynamic stimuli, increasing sample size, and controlling for comorbid alexithymia. Furthermore, the ideas posited by the two-pathway model can be tested concurrently.

Conflict of interest

All the authors declare no conflict of interest.

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