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DOCTORAL THESIS

“The Social Gaze: social visual orienting in typical and atypical development.”

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Gaze plays a cardinal role in human interactions – enabling non-verbal communication between parent and child, teacher and pupil and friends that play poker. As gaze pervades social interactions, it has been one of the most studied topics in various fields, from developmental psychology to cognitive neuroscience.

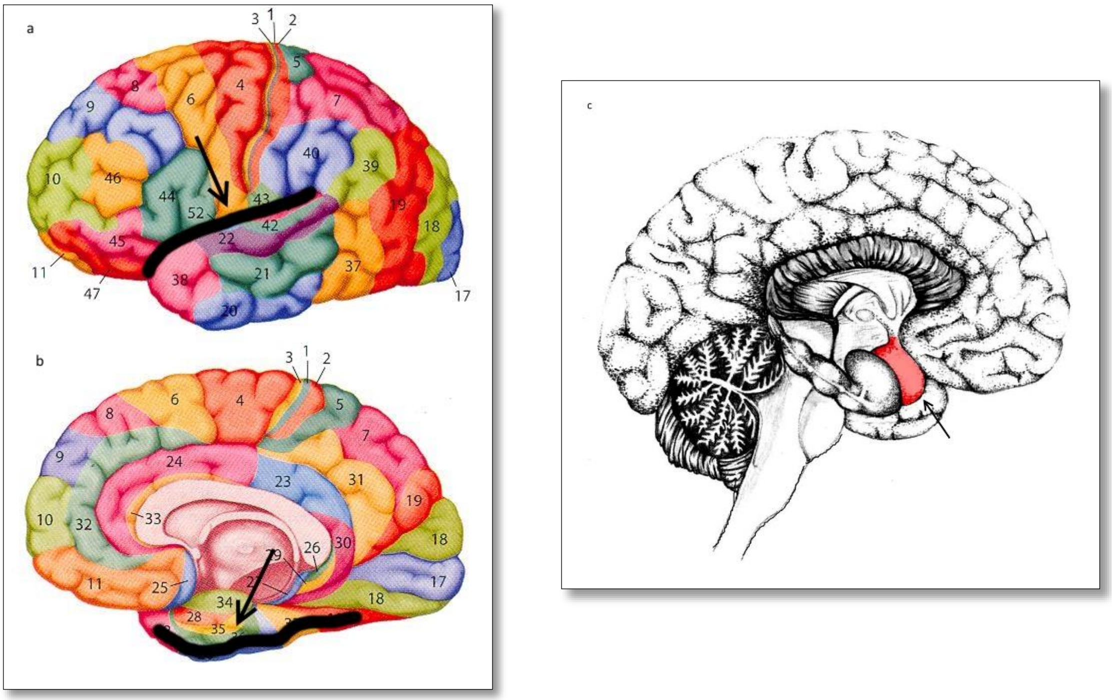
Gaze delivers substantial social information. Therefore, various related behaviours, including gaze-seeking, following, and reading, are considered of primary importance for Social Cognition – the complex, functional unit that enables humans' interaction (Frith & Frith, 2007). Gaze plays a conspicuous role during a face-to-face contact (Guillon, Hadjikhani, Baduel, & Rogé, 2014) and non-verbal communication (Emery, 2000). Human's tendency to orient to and look at other people, in particular their faces and eyes, has been termed visual social attention (Guillon et al., 2014).

The way we orient/look at other people gives rise to prototypical behaviours including face-orienting, eye-contact, and gaze-following. Face-orienting describes the strong tendency to look for, track and explore faces, compared to other stimuli. Eye-contact consists of looking each other in the eyes; in experimental settings, a face whose gaze is directed forward – called direct gaze – mimicries the presentation of a social partner attempting to establish eye-contact. Gaze-following is literally the tendency to follow the direction of the gaze of others, and it is an index of joint attention, consisting of two persons sharing their focus on the same item.

Figure 1: Human infants orient to and look at faces from birth; they also are prone to establish eye-contact (on the top). From infancy, humans follow the direction of the gaze of others; this behavior promotes joint attention (on the bottom).

Behaviours related to social attention are associated with the specific activation in areas of the Social Brain – i.e., cortical regions, in particular the Superior Temporal Sulcus and the Fusiform Gyrus (Beauchamp, 2015; Hooker et al., 2003), and subcortical structures, in particular the Amygdala (Emery, 2000).

Figure 2: a) above: on the left lateral surface of the brain, the Superior Temporal Sulcus is highlighted with a thick, black line and an arrow; b) on the right internal surface of the brain, the Fusiform Gyrus is highlighted; c) on the left internal surface of the brain, Amygdala is indicated by an arrow.



As humans are provided with effective skills for detecting and decoding gaze information, they process rapidly and effectively the face and its internal features, including the eyes. The appearance of human eyes is unique: the proportion of white surface – the sclera – is more extended than in other animals, primates included, and the high contrast between sclera and iris render eyes an explicit indicator of gaze direction (Kobayashi & Kohshima, 2001; Tomasello, Hare, Lehmann, & Call, 2007). Therefore, it has been suggested that the shape and arrangement of the eyes and visual social attention have evolved together with the pressure of better socio-communicative skills in humans (Tomasello et al., 2007).

Figure 3: Tomasello and colleagues (2007) proposed that the shape of the human eye evolved along with the emergence of structured cooperative behavior in human society. On the top, the eyes of a human, with the thick surrounding sclera. Below, the eyes of our close cousin, a chimpanzee, with the vast amount of the eye surface covered by the dark iris.

The development of Social Gaze[1]

Face configuration is recognizable from humans' earliest start – birth. The face contains high-contrast elements, whose natural arrangement is attractive for newborns. From the earliest days of life, infants have a tendency to orient to and track faces (Johnson, Dziurawiec, Ellis, & Morton, 1991). Face-orienting contributes to the orientation towards the conspecifics, thus having an adapting function (Johnson, Senju, & Tomalski, 2015). The spontaneous movements of the head and the eyelids attract the attention on the face and promote gaze-following (Farroni, Johnson, Brockbank, & Simion, 2000). The shape and reciprocal arrangement of the eyes, the mouth and the nose improves identity and sex recognition (Itier & Batty, 2009), while facial expressions provide information about a person's emotional state (Haxby, Hoffman, & Gobbini,

[1] The following paragraphs are adapted from the article: Del Bianco, T., & Venuti, P. (2017). The Gaze of Others: Atypical development of early social orienting in Autism Spectrum Disorder. Psicologia Clinica Dello Sviluppo, 21(3). http://doi.org/10.1449/88499

2002). The direction of gaze informs about the focus of attention and future intentions of others (Emery, 2000).

After attention is rapidly shifted to the source of social information, for instance a face, sustained focus allows for more sophisticated processing of face information, and requires the activation of the attentive regulation system (Mundy, Sullivan, & Mastergeorge, 2009). Early and late stages of cortical activation associated with face inspection confirm that face processing is a dual process. In particular, a late variation of activity, after the early waves of activation that follow the stimulus onset, indexes attentional engagement and extended processing (Choi & Watanuki, 2014; Sreenivasan, Goldstein, Lustig, Rivas, & Jha, 2009; Weinberg & Hajcak, 2011).

From the developmental point of view, behaviors with early emergence, including eye-contact, gaze-following, and attention to the face in terms of both fast orienting and sustained focus, constitute the building-blocks of complex interactive behaviors, such as joint attention. Furthermore, initial differences in the social gaze predict the development of specific social abilities: episodes of joint attention in infants predict linguistic, cognitive and mentalistic abilities, also called Theory of Mind (Charman et al., 2000). The most studied example of atypical development in relation to visual social attention is Autism Spectrum Disorder (ASD). ASD is a condition with atypical neurodevelopment with relatively high prevalence, estimated between 1 – 1.5% (Baird et al., 2006; Elsabbagh et al., 2012; Fombonne, 2009), and a high genetic heritability (i.e., siblings of children with ASD are at higher risk of developing the condition compared to the general population; Grønborg, Schendel, & Parner, 2013). ASD is characterized by impairment in the socio-communicative domain, stereotyped movements and/or restricted interests (American Psychiatric Association, 2013); the weakened ability of establishing social interactions may be due to a primary impairment of early social-orienting skills, one of which is social gaze. Persons with ASD have difficulty using gaze in social interactions, and the differences in joint attention predict language development and severity of symptoms (Dawson et al., 2004; Mundy, 2016; Yoder, Stone, Walden, & Malesa, 2009).

In the following paragraph, we will briefly overview the technique that has become the gold standard for the study of social gaze: eye-tracking. Afterwards, the characteristics of gaze-related behaviour in typical and atypical development will be presented.

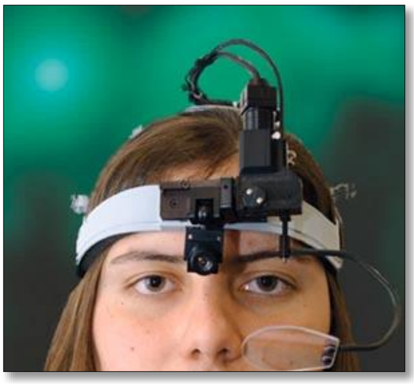
The new advancement in Research Methodologies: eye-tracking

Studying the social gaze means studying the location of the gaze of someone. The first target of a fixation, the velocity of a gaze shift and the length of one look provide additional and valid information for answering increasingly complicated questions, including the parts of a face that attract the most attention, the conditions that facilitate gaze-following and the distribution of social attention in the natural environment. For many, successful years, questions concerning the social gaze have been challenged with observational assessments, where the gaze was recorded and its shifts were manually coded during the experiment or afterwards. These procedures were well established but retained limitations, including the scarcely naturalistic settings, the partial reliability of the coder and the small amount of data collected from the experiment.

In the sense of impartiality, data complexity and quantity, eye-tracking represented a revolution. Eye-tracking devices record eye-movements in real time while the participant is looking at a scene. Eye-tracking exists in the psychological research field from the second half of the XX century, however, it became extremely non-invasive, portable and accurate at the threshold of the XXI century (Holmqvist et al., 2011).

Nowadays, most research with infants, children, and developmental disorders uses a specific type of remote eye-tracking that works with corneal-reflection (Gredebäck, Johnson, & von Hofsten, 2010). First, the eye-tracker is remote, meaning it is located in front of the participant, and not mounted on her head like older models (see Figure 3). Second, the eye-tracker contains a sensor that releases invisible rays on the infrared spectrum and reuptake their reflection on the surface of the participant's eyes, the cornea. The mapping of the center of the cornea yields an extremely robust estimate of the position of the gaze (Guillon et al., 2014). Therefore, corneal-reflection eye-trackers allow consistent head movements, certainly advantageous in research with populations that may not be compliant to sit still. One practical example of an issue that contemporary eye-tracking devices contributed to overcome is the obvious impossibility of giving strict instructions to the youngest participants.

Figure 4: on the top, a head-mounted eye-tracker; below, a remote eye-tracker placed at the bottom of a computer screen.



The minimum size, versatility, and accuracy have made eye-trackers an invaluable resource for minutely investigating the distribution and regulation of social attention in infants, children and individuals with disabilities. Eye-tracking allows the investigation of eye-movements associated with a precise event or contextual factor. Therefore, it provides insight on the distribution of social attention during development and in atypical development (Gredebäck, Johnson, et al., 2010).

The Social Gaze and Related Behaviours in Typical Development

Face-orienting

Human adults orient preferentially to images of faces that are competing with other stimuli (Shah, Gaule, Bird, & Cook, 2013). Evidence shows that this preference is likely to be regulated by specific properties of the stimulus – primarily, the special configuration (see Figure 5) and contrast polarity of the face (Stein, Peelen, & Sterzer, 2011). This phenomenon is invariant when adults are presented with schematic rather than realistic faces, as they orient equally faster to either stimulus, suggesting that the detection of a face may be partially independent from face-processing (Tomalski, Csibra, & Johnson, 2009). The same factors influence the orientation to specific features of a face, such as eye-gaze (Tipples, 2005). Infants (Johnson et al., 1991) and children (Shah, Happé, Sowden, Cook, & Bird, 2015) show an overlapping face-orienting behaviour. Even though the preferential orienting may disappear when other interesting items are present (like toys), infants tend anyway to look longer at faces (DeNicola, Holt, Lambert, & Cashon, 2013). It has been suggested that this powerful bias is subtended by a strong visual preference for faces at birth (Gliga, Elsabbagh, Andravizou, & Johnson, 2009) – or even earlier, as emerged from a recent investigation of foetuses (Reid et al., 2017). The emergence of this behavior has been related to its socio-evolutionary adaptive value and it may be a foundation of the sophisticated face expertise that develops until adulthood (Johnson et al., 1991, 2015).

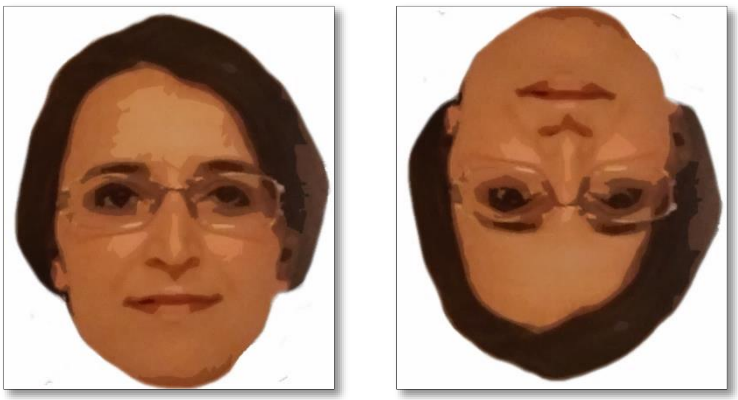
The inborn predisposition allows massive exposure to faces from the very first hours after birth (Simion & Di Giorgio, 2015). In the following months, in line with further brain development (Johnson, 2011), the maturation of inhibitory attentional mechanisms (Frank, Vul, & Johnson, 2009) and the experience-dependent refinement of face-processing abilities (Simion & Di Giorgio, 2015) reinforce visual preference for faces (Frank et al., 2009). First, the emergent capacity of voluntary controlling attention and inhibiting automatic shifts, contributes to the emergence of flexible and intentional engagement episodes (Fox, Henderson, Marshall, Nichols, & Ghera, 2005). Secondly, early visual experience may be particularly important for the refinement of face-processing abilities: in one study, young adults that had visual deprivation showed normal accuracy and latency of face detection, but atypical underlying neural activity, as measured by electroencephalogram, compared to controls (Mondloch et al., 2013). Specifically, the participants showed larger event-related potentials (ERP) P100 – a positive peak of cortical activity related to visual processing – and N170 – a face-specific negative deflection of cortical activity. Notably, the augmented amplitude was proportional to the duration of visual deprivation earlier in their life. Furthermore, in adults, there is evidence that faces preferentially engage attention and act as powerful distractors of attentive resources (Palermo & Rhodes, 2007).

Eye-contact

The fact that humans spent a substantial amount of time engaged in mutual eye contact (Wang, Newport, & Hamilton, 2011) when interacting with each other suggests its pivotal importance for social life. Exchanging looks enhances a series of major human resources: motor performance and imitation (Castiello, 2003), face recognition (Hood, Macrae, Cole-Davies, & Dias, 2003), mimicry (Wang et al., 2011) and interpersonal liking in general (Mason, Tatkow, & Macrae, 2005). As with face, humans are particularly efficient and fast in detecting a face displaying a direct gaze (Senju, Hasegawa, & Tojo, 2005). Translated into realistic terms, people are biased to establish eye-contact with someone in front of them and looking straight at them.

This behaviour has been observed from very early in development: newborns preferentially orient to faces that exhibit a gaze directed forward, i.e. a direct gaze (Farroni, Csibra, Simion, & Johnson, 2002). Such a preference is modulated by the presentation of direct gaze in the context of a face with standard configuration (upright versus inverted; see Figure 5) and a straight-ahead position (perception of direct gaze in the context of averted head angles is delayed; Farroni, Menon, & Johnson, 2006).

Figure 5: on the left, an upright face (standard configuration); on the right, the same face inverted (non-standard configuration).



From early in development, perceiving a direct gaze and establishing eye-contact influence cognitive processes and behavior (Senju & Johnson, 2009). For instance, observing a face displaying a direct gaze facilitates four-months-old infants' recognition of the same face (Farroni, Johnson, & Csibra, 2004). Moreover, an initial period of eye-contact increases the efficacy of the gate signal in directing the infants' attention to one direction (Farroni, Mansfield, Lai, & Johnson, 2003). The effect of eye-contact on visual behavior – like visual preference, recognition, and attention orienting – has precise neural correlates, as measured by negative variations of brain potentials occurring in restricted time windows after the observation of a face with direct gaze (Event-related potentials, ERP; Farroni et al., 2004). Furthermore, eye-contact changes the processing of objects. When an object was presented and hidden by an experimenter establishing eye-contact with the participant, a 9-months old infant easily detected changes in the object identity (Okumura, Kobayashi, & Itakura, 2016). On the contrary, she focused on both changes in identity and location when eye-contact was not established. The authors hypothesized that eye-contact biased the infant to encode general, identity information, rather than transient information about location. The neural activity associated with objects processing encounters a similar pattern of change in the presence of eye-contact. An object that has been presented by an experimenter that established eye-contact induced a larger Positive Component, associated with enhanced recognition (Hutman et al., 2016). Some authors proposed that eye-contact induces a shift of the encoding of an object, functional to the establishment of a communicative and pedagogical context (Senju & Johnson, 2009; Yoon, Johnson, & Csibra, 2008).

Gaze-following

Gaze-following is the behavioral response to others' initiative of sharing attention on one object or one position in space – therefore, it is an important component of Joint Attention (Brooks & Meltzoff, 2005). A first step of the mechanism of gaze-following is the facilitation of overt shifts of attention congruently with the direction of gaze (Driver et al., 1999): all humans tend to shift their eyes into the direction of the gaze of another. Fast and reflexive (i.e., beyond voluntary control, even if the gaze signal is uninformative) gaze shifts characterize this widespread phenomenon, known as "gaze-cueing effect" (Friesen & Kingstone, 1998; Frischen, Bayliss, & Tipper, 2007). This effect, together with the detection of head and body orientation (Hietanen, 2002), enables the recognition of others' direction of attention and, eventually, the establishment of joint visual attention (Langton & Bruce, 1999).

From the developmental point of view, gaze-following is a fundamental ability that makes the first attention sharing episodes possible early in infancy (Mundy & Newell, 2007), even though it remains unclear whether infants understand the referential meaning of gaze (Butterworth, 1991; Meltzoff & Brooks, 2007). From the behavioural point of view, an infant as young as 3 months of age follows an adults' gaze to close objects (Gredebäck, Fikke, & Melinder, 2010). An infant's capacity of gaze-following progressively expands across the first year: by 12-18 months, she can follow the caregiver's gaze to targets outside of her field of view (Butterworth & Jarrett, 1991). This observation has been interpreted as a transition between and "ecological-geometrical" stage, when gaze-following is limited by the immature cognitive and oculomotor system, to a "representational" mechanism, true sign of the joint engagement between two individuals (Butterworth & Jarrett, 1991). Furthermore, the fact that the adult is looking at an object increases the baby's sustained attention and makes her interest stick to target (Yu & Smith, 2016). The frequency of gaze-following varies according to individual differences (e.g. temperament; Markus, Mundy, Morales, Delgado, & Yale, 2000) and is proportional to future abilities, such as language skills and executive functions. In fact, following the gaze of others helps infants to connect a verbal label, often produced by the adult while looking at something, to its referent; therefore, the frequency of gaze-following longitudinally predicts linguistic abilities, including vocabulary extension

(Brooks & Meltzoff, 2008). Perceptual factors – like the upright configuration of the face (as opposed to an inverted configuration; Farroni et al., 2003), the movement of the head and pupils (Farroni et al., 2002) and the chromatic polarity of the eye (i.e. the pupil is black, the sclera is white; Farroni et al., 2005; Ricciardelli, Baylis, & Driver, 2000) – influence gaze-following. In other words, if the face and eyes that provide the gaze signal do not present the typical configuration, properties, and colors, gaze-following does not occur. Therefore, sensitivity to the face typical configuration and to biological movement are considered as building-blocks of gaze-following (Farroni et al., 2003).

The study of gaze-following has particularly benefited of eye-tracking technology, since it allowed naturalistic stimuli and settings and introduced a higher temporal – i.e. the relation between eye-movements and a single stimulus – and spatial accuracy – i.e., aspects of the stimuli that attracted most of the eye-movements (Gredebäck, Fikke, et al., 2010). A longitudinal eye-tracking study elucidated the early emergence of gaze-following, around 3-4 months (Gredebäck, Fikke, & Melinder, 2010), and its intimate connection with communicative hints provided by the adults, like eye-contact and infant-direct-speech (Senju & Csibra, 2008). Similarly to eye-contact, gaze-following modulates the subsequent object processing; an infant with typical development looks longer at the target object after gaze-following (Senju et al., 2015; Thorup, Nyström, Gredebäck, Bölte, & Falck-Ytter, 2016). Furthermore, gaze-following is associated with enhanced neural processing of the target object (Okumura, Kanakogi, Kobayashi, & Itakura, 2017; Senju, Csibra, & Johnson, 2008). Whether this effect is explained by a build-in understanding of the referential value of gaze is controversial (Senju, Csibra, et al., 2008). Nonetheless, the coupling of gaze-following and enhanced object processing gives an outstanding contribution to cognitive development, as it longitudinally predicts linguistic abilities (Okumura et al., 2017).

Even if research has shifted the emergence of gaze-following in the first half of the first year of life and proved its relevance for cognitive development, several models of gaze-following emergence exist. Theoretical accounts may be divided among four families that are briefly explained in Table 1.

Table 1: A brief overview of theoretical accounts on gaze-following emergence.

Theoretical Address		Reference	Essentials
Dynamical Systems		(Thelen & Smith, 2006)	A behaviour emerges from the disturbance of a precedent state of equilibrium: different paths are possible (e.g., hand-following along with gaze-following).
Socio-cognitive accounts	Natural Pedagogy	(Csibra & Gergely, 2009)	Gaze-following is the behavioural expression of a referential expectation and occurs only in specific contexts (e.g., after eye-contact)
	Nine-months Revolution	(Tomasello, 1995)	Gaze-following emerges when the infant develop a sense of individual and shared intentionality.
	Like-me Hypothesis	(Meltzoff, 2013)	Infants grasp that others are similar to the self and follow the gaze of others to gain their same visual experience.
Reward Learning	PLeASES Theory	(Deák, Triesch, Krasno, de Barbaro, & Robledo, 2013)	Infants progressively learn to associate the gaze of others to interesting sights; general attentive and learning mechanisms

		influence gaze-following.

Nowadays, not all the theoretical predictions of the nominated visions have been empirically tested and compared. In particular, two accounts stand out for the contrast between their visions on the developmental origin of gaze-following. One interpretation sees gaze-following as the product of general-domain learning processes (the PLeASES Theory; Deák et al., 2013; Triesch, Teuscher, Deák, & Carlson, 2006). This theory rests on the evidence suggesting that infants learn to follow gaze by means of operant conditioning, in which sharing attention with the other serves as the reinforcing stimuli (Triesch et al., 2006). To these authors, general inter-individual differences, such as an infant's delayed visual disengagement and difficulty to process gaze, rather than specific situational factors may be more important in influencing gaze-following (Deák et al., 2013). Some evidence about the time course of gaze-following favours this explanation. Gredebäck and colleagues (Gredebäck, Theuring, Hauf, & Kenward, 2008) found that infants around 6 months of age required more time to process gaze direction than older infants. Accordingly, infants' gaze-shifts had also a long latency (3-5 sec in D'Entremont, 2000), a fact that has been related to the difficulty in disengaging from a face presented in the centre of the infant's visual field (Hood, Willen, & Driver, 1998). Deák and colleagues (2013) conjectured that "*When an infant looks at a caregiver's face or a toy, habituation begins, and over time the probability of a gaze shift gradually increases.*" (p. 186-187), thus hypothesizing that habituation to a face facilitates the disengagement and promotes a subsequent gaze-shift.

To an alternative theoretical framework, namely the "Natural Pedagogy" (Gergely & Csibra, 2013), gaze-following is not part of a general-domain learning process, but rather determined by a specific, innate sensitiveness. To this account, infants are specifically sensitive to communicative signals of other people, such as eye-contact and infant-directed speech (defined "ostensive cues"), that deliver the communicative intention of the social partner and gaze-following naturally follows ostensive cues. Eye-contact has been defined as the "*the most obvious ostensive signal in human communication*" (p. 149, Csibra & Gergely, 2009), as it systematically attracts attention to the communicator's face nearly from birth (Senju & Johnson, 2009). Infant-directed speech, also termed "motherese", has a highly recognizable prosody, characterized by high and broad pitch, amplitude variation and slow velocity (Csibra & Gergely, 2009). Its function is more specific to dyadic interactions than eye-contact, as it disambiguates the communicative situation to the preverbal infant that has no access to semantic information (Csibra & Gergely, 2006). Furthermore, the theory highlights that the *temporal contingency* is important for the reception of communicative intent (Csibra & Gergely, 2006). The authors emphasize that, in the context of gaze-following, temporal contingency may even have a more important role than eye-contact, as it has been observed that infants responded with gaze-following in the absence of a face (and eye-contact), as long as contingent feedback was provided (Csibra & Gergely, 2006). Time contingency operates as infants perceive, by expecting an action from the social partner after she being still for a period (Csibra & Gergely, 2006). Even though the duration of such a period has not been specified, we imply that it should not exceed the infants' capacity of retaining information.

The first study presented in this thesis will directly compare the predictions of these two alternative theories on one of the determinants of gaze-following during the first year of life: the duration of the time of presentation of the face prior to a gaze signal.

The Social Gaze and Related Behaviours in Atypical Development

Face-orienting

There is consensus on the observation that people with ASD allocate less attention to faces and their internal features, eyes and mouths (Chita-Tegmark, 2016). Nonetheless, empirical findings are mixed, with some studies not succeeding in the detection of between-group differences. Children and adults with ASD tend to look less at faces in a significant way (Guillon et al., 2014), even if contrasting results (Freeth, Chapman, Ropar, & Mitchell, 2010) or more subtle differences have been reported (Benson, Piper, & Fletcher-Watson, 2009; Fletcher-Watson, Leekam, Benson, Frank, & Findlay, 2009). With regard to the proportion of face-orienting, measured as the first looks to the face or the eyes, recent studies showed that it is not significantly different between infants with typical and atypical development (Elsabbagh, Gliga, et al., 2013) but it is generally decreased in childhood and adulthood (Guillon et al., 2016; Kleberg, Thorup, & Falck-Ytter, 2017). Likewise, the timing of the shifts (the latency) of children with high-functioning ASD is comparable to the one of typical peers (Fischer, Koldewyn, Jiang, & Kanwisher, 2014), but it has been reported to be slower in individuals with a moderate to severe condition (Riby, Hancock, Jones, & Hanley, 2013). The alteration of social orienting may be modulated by contextual factors (Guillon et al., 2014), for instance, images of eyes and other objects, preceded by an alerting sound (Kleberg et al., 2017). In that study, the authors obtained opposite patterns: an increased trend of orienting toward eyes in children with ASD, and decreased in children with typical development.

Given the apparent correlation between age, functioning and face-orienting, suggested by cross-sectional comparisons, emerging longitudinal studies have attempted to clarify the pattern of change of face-orienting in atypical development. Gliga and colleagues (2014) found that the basic aspects of face processing are intact in at-risk infants (i.e., siblings of children with ASD) younger than 12 months. Therefore, the authors hypothesized that the relation between atypical development, attention to faces and subsequent face processing abilities may have a different expression. Accordingly, the follow up of the same study showed that those infants pertaining to the at-risk group that showed normal face-orienting but atypical sustained attention to the face at 6 months, had poorer face processing skills at 3 years (de Klerk, Gliga, Charman, & Johnson, 2014). Additionally, high-risk infants that later developed the condition showed atypical visual scanning, with shorter individual fixations, irrespective of stimulus type (Wass et al., 2015).

Importantly, the aforementioned studies used static photographs presented in simplified arrays of visual items. With realistic video clips and verbal content (for instance, an actor greeting and talking to the participant), individuals with ASD showed diminished face-looking time (Chawarska, Macari, & Shic, 2012, 2013). A study showed that individuals with ASD did not increase the fixation duration on a face when it was moving, as opposed to a still portrait, differently from individuals with typical development (Rigby, Stoesz, & Jakobson, 2016). The authors hypothesized that individuals with ASD may improperly process motion cues resulting in a different modulation of visual attention.

A related question concerns the influence of Autistic Traits – the behavioral and cognitive expressions of the individual collocation on the Autism Spectrum (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001) – on the regulation of face-orienting in people without atypical development. On this point too, evidence is limited and mixed. Freeth and colleagues (2013) reported no effect of Autistic Traits, measured with the

Autistic Quotient (AQ) (Baron-Cohen et al., 2001), on the level of attention to the face. However, another study reported a negative correlation between AQ and the proportion of looks to faces showing a gaze directed to the participant (Chen & Yoon, 2011). Nonetheless, other results suggest that subtle expressions of impairment in the social domain may relate with social orienting. For instance, another trait that substantially influences face-orienting is anxiety. People with high levels of social anxiety, compared to people with low levels, sustained less their focus on images of faces (Garner, Mogg, & Bradley, 2006) and tended to look away sooner from emotional faces (Mansell, Clark, Ehlers, & Chen, 1999). Furthermore, anxiety problems are very common among people with ASD (White, Oswald, Ollendick, & Scahill, 2009). Furthermore, empathy, related both to ASD and Autistic Traits, and to anxiety, might be expected to influence social orienting. Empathy is the ability of putting oneself in another's shoes, understanding her feelings, predicting her next action and eventually helping her. People with ASD score lower in the assessment of the levels of empathy (Baron-Cohen & Wheelwright, 2004) and one aspect of empathy is related to anxious feelings, due to the self-oriented emotional reaction: the Personal Distress (PD) subscale of the Interpersonal Reactivity Index (IRI) (Eisenberg et al., 1989). PD describes states of anxiety and internal discomfort when witnessing the distress of others (Davis, 1983). Individuals with Asperger Syndrome (i.e., ASD with unimpaired verbal abilities and intelligence; Ehlers et al., 1997) scored higher on PD (Hagenmuller, Rössler, Wittwer, & Haker, 2014; Rogers, Dziobek, Hassenstab, Wolf, & Convit, 2007). It may be expected that empathic traits influence Social Attention, and that PD has a negative effect, but the field have been scarcely explored. However, it has been reported that Personal Distress is associated with avoidance of distressed others (Eisenberg et al., 1989) and correlates to brain activity when a person is observing a face (Choi & Watanuki, 2014).

As the evidence is inconsistent, alternative explanations are many and range from heighten arousal to bottom-up visual regulation imbalance (Chita-Tegmark, 2016).

A common explanation that encompasses the effect of ASD and anxiety on attention to the face is the hypothesis that faces may be too stimulating for individuals with ASD, high levels of autistic traits and/or anxiety, leaving an unpleasant internal feeling due to hyper-arousal (Dalton et al., 2005; Garner et al., 2006). The hypothesis fits also the prediction that the distressful aspect of empathy, PD, may negatively influence attention to the face. An even more interesting hypothesis may be that autistic traits, anxiety and empathy influence Social Attention jointly. As previously mentioned, they may emerge from a common background of heightened arousal, thus determining the visual avoidance of faces.

Nonetheless, the uneven alteration of face-orienting and face-looking time may be the consequence of a primary impairment, leading to decreased face expertise but also compensatory mechanisms. To this view, an initial deficit of face-orienting may be present but not sufficient and pervasive difficulties controlling attention may play a role (Elsabbagh, Gliga, et al., 2013). The regulation of attention influences the development of attentive abilities (e.g. distractibility, Colombo et al., 2004) and additional domains (e.g., information processing, Rose, Feldman, & Jankowski, 2001). The second study reported in this thesis addresses this question and investigate face-orienting and face-looking time, as well as the regulation of conventional attentive mechanism, and its effects on attentive selection. In addition, the third study investigates the joint influence of autistic traits, anxiety and personal distress on the attention to the face.

Eye-contact

Eye-tracking studies that addressed where people with ASD look within a face, found that they looked significantly less at eyes at any age (childhood: Campbell, Shic, Macari, & Chawarska, 2014; adolescence: Chevallier, Huguet, Happé, George, & Conty, 2013; adulthood: Klin, Jones, Schultz, Volkmar, & Cohen, 2002). At-risk infants followed longitudinally, decreased their attention to eyes between 2 and 6 months of life (Jones & Klin, 2013). Furthermore, people with ASD prove a difficulty detecting eyes displaying direct gaze, a process that is facilitated in typical development (TD). One study (Senju et al., 2005) used an odd-ball paradigm – where the velocity of the visual detection of a specific element among distractors is analyzed – and showed that children with ASD were slower in detecting a face with a direct gaze. The configuration of the face does not affect the sensitivity to direct gaze of children with ASD (Senju, Kikuchi, Hasegawa, Tojo, & Osanai, 2008; van der Geest, Kemner, Verbaten, & van Engeland, 2002). Direct gaze may have a different effect on the social attention of children with ASD since in one study they tended to look away from a scene more frequently when the actor displayed direct gaze, compared to children with TD (Chawarska et al., 2012). Recent evidence showed that the atypical response to direct gaze might be restricted to a very short time window in at-risk infants. Nyström et al. (Nyström et al., 2017) reported that decreased looking at an adult face in response to direct gaze occurred only during 300 to 1000 milliseconds after the social hint, while it was comparable for the rest of the interaction. While data on the follow up of at-risk children is necessary for evaluating the relationship with the diagnosis of ASD, this finding further highlights that the modulation of the gaze behaviour may be subtly impaired at the earliest stages. The impaired response to direct gaze may affect social attention as well as non-social cognitive tasks: children with ASD performed equally well on a memory task when the experimenter did not establish eye-contact, while the performance of children with TD dropped (Falck-Ytter, Carlström, & Johansson, 2015). Similarly, direct gaze, together with other expressions of social engagement (e.g., emotional displays and vocal remarks) did not reinforce the emotional attunement (Nuske, Vivanti, & Dissanayake, 2016) and imitative behaviour (Vivanti, Hocking, Fanning, & Dissanayake, 2016) in children with ASD compared to a neutral situation, whereas the response of control participants significantly increased. Interestingly, the authors excluded that the divergent modulation may be explained by differences in the attention to the social cues, as they observed no differences in the looking times to the face and eyes of the experimenter between children with ASD and control participants in all conditions (Falck-Ytter et al., 2015; Nuske et al., 2016). Therefore, eye-contact may differently modulate cognitive processing, emotional adjustment and even learning in individuals with ASD.

Gaze-following

Children with ASD spontaneously follow the gaze of others, with a positive influence of the mental age (Leekam, Hunnisett, & Moore, 1998) and the quantity of signals provided together, such as eyes turn plus pointing (Leekam et al., 1998) and eyes plus head shift (Thorup et al., 2016). The effect of gaze-following may be different in persons with ASD, similarly to eye-contact; in fact, children with ASD were equally fast in detecting a target that popped out in the same/in the opposite direction of gaze, while children with TD were faster in the first compared to the second condition (Johnson et al., 2005). Impaired accuracy and delayed latency of gaze-following predict respectively socio-communicative abilities and verbal intelligence in children with ASD (Falck-Ytter, Fernell, Hedvall, Hofsten, & Gillberg, 2012).

Even if differences in accuracy and latency of gaze-following are subtle, children with ASD clearly evaluate differently the object aligned with the gaze of others. A longitudinal study showed that at-risk infants followed gaze to the same extent as non-at-risk infants, but at-risk infants with worst socio-communicative difficulties at the follow up observed the target for shorter periods (Bedford et al., 2012). Congiu et al. (2016) found that children with ASD looked less to a container that hid a target when the experimenter looked at it with the eyes only and without moving the head (even if they did not show difficulty following the gaze cue). These findings may be interpreted as a preserved processing of the spatial information of gaze but an impaired understanding of its referential value or object-directedness (Bedford et al., 2012; Congiu et al., 2016).

Aim of the current thesis

Three eye-tracking studies are presented in this thesis, aimed to investigate the open questions regarding the emergence of Social Gaze and its atypical development, highlighted in the previous text.

Chapter 1: What is the impact of face presentation time on gaze-following?

We present a study focused on gaze-following emergence and one of its putative influencing factors: habituation to the face. According to a reward-learning model proposed by Deák and colleagues (Deák et al., 2013), the more time is given to an infant to habituate to a specific face, the more he/she will be able to disengage and follow the signals coming from that face. In the first study, we specifically addressed this prediction, by manipulating the time of presentation of the face before it provided a directional gaze cue.

Chapter 2: Are people with ASD biased to look at faces? Are there any differences between atypical and typical development in the attentive selection of socially relevant stimuli beyond face-orienting?

In our second study, we investigated the face-orienting response in ASD and we expanded our field of investigation to the general attentive mechanisms. The subsequent attentive selection of the face, after the first, mostly automatic orientation, may play a substantial role in typical/atypical development, since it allows more sophisticate face-processing, as recent evidence highlighted (Elsabbagh, Gliga, et al., 2013; Wass et al., 2015).

Chapter 3: Do Autistic Traits, Empathy and Anxiety influence the attention to the face in the typical population?

In the third study, we investigated the influence of Autistic Traits that are a candidate for modulating the looking time on the faces in the typical population. We tentatively stratified the Autistic Traits with additional characteristics, proven to influence Social Attention in general and often coexisting with Autistic Traits: Empathy and anxious symptoms.

Chapter 1

What is the impact of face presentation time on gaze-following?

As we highlighted in the introduction, gaze-following is a behaviour with early onset and promotes the first shared episodes of attention between an infant and the caregivers (Mundy & Newell, 2007). The current experiment was designed in order to test two alternative research lines on the developmental origin of gaze-following – the PLeASES Theory and Natural Pedagogy – and their predictions on its determinants. To do so, we evaluated the effect of different durations of face presentations before giving a gaze cue. In other words, we tested whether a long presentation of a face increases the rate of gaze-following in 6-7-month-olds. To test this, the babies were exposed to three consecutive phases, showing an adult making eye-contact and greeting the infant with an infant-directed prosody (ostension phase), looking straight to the front with a neutral expression (face presentation phase) and shifting her gaze to a toy (cueing phase). The face presentation phase varied between a short (0.5 seconds) and a long version (5 seconds). According to the different lines of research that we outlined in the introduction, we derived two different outcomes:

1) A longer face-presentation time should enhance gaze-following, because it gives infants more time to process and habituate to the face, allowing a more efficient disengagement from it (in accordance to the PLeASES Theory; Deák et al., 2013)

2) Infants exposed to the long version may be less prone to follow gaze, as they expect a prompt time contingency between the initial ostensive cues and the subsequent gaze shift for establishing a communicative context, despite eye-contact being available for the whole period (in accordance to the Natural Pedagogy Proposal; Csibra & Gergely, 2006; 2013).

Methods

Participants

The final sample consisted of 40 infants (1 excluded for technical failure, 3 for fussiness).

The infants were recruited from a database of parents in Uppsala (Sweden), who had indicated interest in participating in research projects. Parents reported Swedish as a main language and absence of developmental concerns, hearing/seeing problems and premature birth. Table 1 shows mean age in months, socio-economical z-scores[2] (SES) and the proportion of females in the two groups. Since age and SES were not distributed normally, we compared these measures through the Wilcoxon Rank Sum and Signed Rank Test, and we tested potential differences in sex distribution across groups with the Fisher Exact Test, that turned out non-significant (age: W = 234.5, p = 0.21. SES: W = 197.5, p = 0.25. Sex: p = 0.53). After participating the study, the parents were given a gift card of the value of 10 KR (about 10 euros).

Table 2: personal information; N = number, M = mean, sd = Standard Deviation, SES = socio- economical z-scores, F:M = females:males.

Condition	N	Age [M (sd)]	SES [M (sd)]	F:M
Long	21	6.74 (0.7)	0.13 (1.07)	11:10
Short	19	6.47 (0.71)	0.16 (1.03)	12:7

[2] Raw scores (1) and z-scores (2) were calculated through the subsequent formulas:

$$1.\ \frac{Y + I}{2} \qquad 2.\ \frac{m - M}{SD}$$

Where Y = years of education, I = Tax Bracket (1-7), m = individual mean, M = sample mean, SD = sample standard deviation.

Tools

Apparatus

The videos were presented on the 1280 x 1024 integrated monitor of a Tobii T120 eye-tracker; the experiment was programmed with the software Tobii Studio (Tobii Technology, Stockholm).

Stimuli

Each infant was assigned to one experimental condition (Long or Short conditions) and watched the same 12 videos, each composed of 3 phases (ostension, face presentation and cueing) with the only variation of duration of the face presentation phase. Each video contained a sequence of:

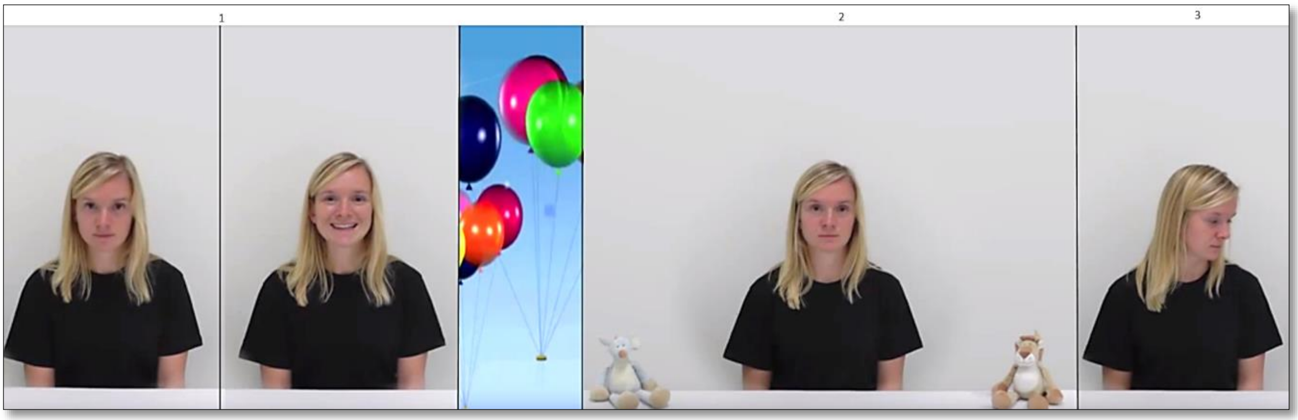
1) Ostension phase (6 seconds): the model raised his/her head and his/her eyebrows, smiled and looked forward; he/she greeted the infant in Swedish (i.e.: "*Hej, är det du som kommer dag*!", "*Hej, välkommen hit*!" translated as "Hi, it is you that came today!" and "Hi, welcome here!"), using an infant-directed prosody. A brief animated attention grabber (3 s) followed the ostension phase with the purpose to attract the infant's attention to the centre of the screen.

2) Face presentation phase (5 seconds in the Long Condition, 0.5 seconds in the Short Condition): the model looked forward with a neutral but friendly expression.

3) Cueing phase (5 seconds): the model moved his/her head (2 seconds) and looked to the left/right object (target object).

In all the clips, the model wore a black t-shirt and sat behind a table, in front of a blank wall; in segment 2 and 3, two toys were placed at a 15 cm distance at either side of the actor. The identity of the model and toys varied in the 12 videos, with 3 persons (2 males and 1 female) and 2 couples of toys (1 of stuffed mice, one of puppets) alternating as model and targets. The model's looks were counterbalanced to the left and to the right.

Figure 6: a series of screenshots showing cutouts of the consecutive phases seen by the infant



Procedure

The experiment took place in a diffusely well-lit room. The infants sat on a car sit, placed on the lap of his/her parent, in front of the eye-tracker. The experiment started with a short, 5-point calibration procedure, with a colourful ball shrinking and expanding at the corners and at the centre of the screen, synchronously with a sound. The calibration was repeated until all five points were sampled. Successful calibration was achieved with no more than 2 attempts in all cases (for additional details about the calibration, see 'Additional Materials' at the end of this chapter). During the experiment, 6 entertaining videos (representing colourful and moving shapes with musical accompaniment) were presented every two trials; if the infant was calm and attentive, the experimenter skipped the entertaining video and proceeded with the following trial. On average, the duration of the experiment was about 5 minutes for the Short Condition and 7 seven minutes for the Long Condition.

Data Analysis

Preliminary Analysis

Data reduction

For the calculation of the eye-movements, a Tobii Fixation filter was applied to the raw data (eye selection: average; velocity threshold = 35, distance threshold = 35); areas of interest (AOIs) were drawn on the head of the model and the two objects. “Correct” (from the face of the model to the target object) and “incorrect” (from the face of the model to the non-target object) first gaze-shifts were calculated though a script developed in R (R Core Team, 2016) that compared the time to first fixation on the head and on the two objects during the cueing phase. The script assigned 1 point to each correct gaze shift and -1 to each incorrect gaze shift. When the participants did not look at the face and/or at the target objects during the cueing phase (i.e., time to first fixation on the head and/or fixation on the two objects corresponded to zero), the script assigned 0 points.

Valid Trials

As the validity (i.e., the measure of the traceability of the eyes, from optimal at 0 to complete data loss at 4) of the samples did not vary between participants and trials (see ‘Additional Materials’ for further details), we adopted the number of gaze shifts from the head to any of the two targets as a criteria of inclusion (Gredebäck et al., 2008). We considered a recording as valid if the infant made one gaze shift from the head to any of the two targets in at least 3 trials (25% of the total number of trials, 12). This behaviour is considered as a signal that the infant focused on the stimulus, major prerequisite for the correct processing of its elements (Gredebäck et al., 2008). Thus, we included 15 infants in the Long Condition and 12 infants in the Short Condition; after the cleaning process, the experimental groups were still comparable for age, SES and sex (for details, see Table

A of ‘Additional Material’). In order to control for possible differences concerning the number of valid trials between the two groups, we conducted the Wilcoxon Rank Sum and Signed Rank Test, that did not turn out significant (Long Condition: M = 5.81, standard deviation = 3.71; Short Condition: M = 5.33, standard deviation = 3.05; W = 210 , p-value = 0.56).

Difference Score

We calculated the Difference Score (DS) by subtracting the number of incorrect gaze shifts from the number of correct gaze shifts. Corkum and Moore (1995) first introduced this measure, that is widely used for estimating infants’ tendency to follow the gaze of others. A DS significantly above zero indicates that the infant reliably followed the gaze-cues (Moore & Corkum, 1998).

Main Analysis

First, we ruled out the possibility that the infants looked at both targets randomly, by comparing the average DS with 0 with one-tailed Student’s T-Tests. If the infants showed a preference for the cued object, motivated by the model’s gaze, the difference between the DS and 0 should turn out statistically significant. As the models and the objects differed in their physical appearance, we checked if the infants showed a visual preference associated with the individual model/object. Furthermore, we checked if the infants showed a bias for looking to the left/right side of the screen: these latter tests were carried out with multiple Wilcoxon Tests, assuming the models/objects/side as independent variables. Finally, a Student T-Test assessed if the average DS differed between the two experimental conditions[3]; the result of the final test evaluated our two

[3] As the DS was distributed normally (Shapiro Wilk Normality Test: W=0.95, p=0.18).

initial hypotheses and unveiled whether a prolonged face presentation time enhanced/disrupted gaze-following.

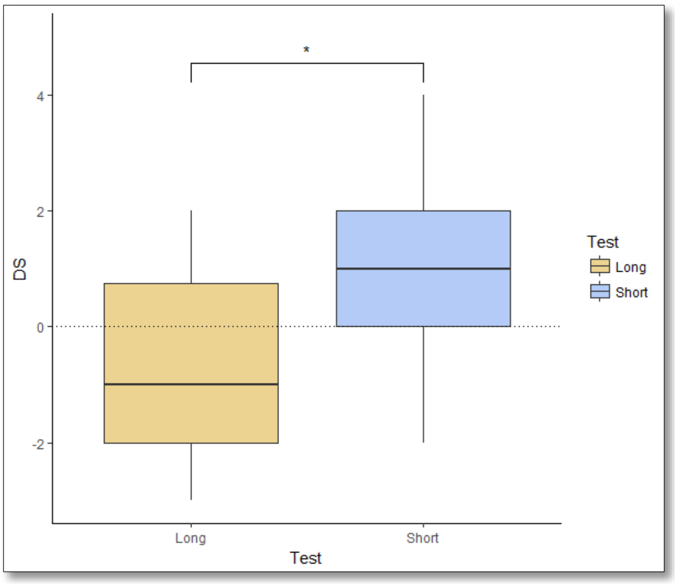
Results

The first t-tests showed that only the DS in the Short Condition was significantly different from 0 (Long Condition: M = -1.2, standard deviation = 2.3, t(14) = -2.02, p-value = 0.97; Short Condition: M = 0.91, standard deviation = 1.67, t(11) = 1.89, p-value = 0.04).

The differences in the DS based on the individual model, the target object and the direction of the cue turned out non-significant (Actor: W= 1.52, p-value = 0.47. Object: W= 306, p-value = 0.3. Cue direction: W= 473.5, p-value = 0.06).

The difference between the DS in the Long and Short condition resulted significantly different (t(24.82) = -2.76, p-value = 0.01, Cohen’s d = 1.04), with an average DS in the Short Condition being significantly higher than the DS in the Long Condition. The following plot (Figure 2) shows the average and median values of the DS scores in the two conditions.

Figure 6: boxplot representing the average, standard deviation and median of the DS relative to the two experimental conditions.



Discussion

In our study, a longer face presentation time did not facilitate gaze-following. Instead, the DS of infants assigned to the Long Condition was below zero, signaling a high error rate in that condition. Such finding rejects the proposal that habituation to the face may be beneficial at this age. The significant difference between the DS, with a higher average value and an above chance performance in the Short Condition, suggests that infants’ gaze-following is more frequent when a gaze-cue is shortly preceded by ostensive cues (eye-contact and infant-directed speech). The temporal contingency between the initial greetings and the gaze-shift boosts the communicative expectation of the infant, possibly for a limited period. It is also noticeable that eye-contact was present for the whole duration of the face presenting phase in both conditions, suggesting that eye-contact alone is not sufficient to maintain the expectation of a subsequent gaze-cue. gaze-following might be more easily elicited when a communicative context is established by multiple cues (eye-contact, infant directed speech and positive affect), rather than be a direct consequence of a specific ostensive cue. Future research could address this topic by manipulating the amount and type of ostensive cues presented simultaneously.

Furthermore, the negativity of the average DS resulting in the Long Condition is intriguing. Since we used the same videos in both conditions and we manipulated only the length of the face presentation phase, we exclude that it may be caused by details of the videos. We report that infants assigned to the Long Condition performed an high number of gaze shifts in the first 2 seconds of the cueing phase (i.e., while the head was still moving; total number of gaze-shifts: 78). By contrast, infants assigned to the Short Condition made a considerably lower number of gaze-shifts in the first two seconds of the cueing phase (only 7). Additionally, gaze-shifts in the Long Condition constituted a considerable proportion of incorrect gaze shifts (0.67). The characteristics or the duration of the cueing phase could not explain the difference in the number of gaze-shifts in the earliest phase of the cueing and of incorrect gaze-shifts, as the clips were identical in both conditions. On a speculative level, we hypothesize that the long face presentation phase might have facilitated early gaze shifts, as it may be predicted by our initial hypothesis, but not the alignment with the direction of the gaze-cues, because of the scarce gaze processing abilities of 6-months old infants. Hence, the absolute higher number of (incorrect) gaze shifts in the Long Condition, compared to the Short Condition. It may be interesting to investigate the effect of a long face presentation time, and thus the facilitation of visual disengagement, at later stages of development, when gaze-processing abilities may have already reached a higher level.

Conclusion

Our finding does not support the hypothesis that a long face presentation time, and the possibility to habituate, facilitate gaze-following, as predicted by the PLeASES Theory

(Deàk et al., 2013). In fact, the esteem of gaze-following, DS, was negative in the Long Condition. Infants assigned to the Short condition instead performed relatively more correct gaze shifts, thus a short Face Presentation Phase facilitated gaze-following, compared to a long phase. This result does not support the idea that having more time for observing the face gives more frequent gaze-following; instead, it suggests that the temporal contingency between ostensive cues – eye contact and infant-directed speech – and gaze-following is important in the first year of life. The observation that, in infants from 6 to 7 months, a long face presentation time boosts the number of early gaze shifts, though they are directed randomly, needs additional examination. Future research might address the effect of a long face presentation time in older children, to investigate whether the situation is stable or subject to developmental change. In addition, manipulations of face presentation time after ostensive cues might inform on the role of temporal consecution of ostensive and gaze-cues and/or disengagement in specific, natural situations.

Additional Materials

Validity Measures

Validity is an estimate of the traceability of the eyes, as measured by the eye-tracker. In the Tobii System, validity ranges from 0 (optimal traceability), to 4 (complete trace loss). With the following analysis, we aimed to ensure that participants assigned to the Long and Short conditions provided data of comparable good quality, as they were not tested simultaneously. The average validity was 0.7 (standard deviation: 0.4) for the long and 0.9 (standard deviation: 0.5) for the short condition. All samples were retained, as the z-scores measuring the deviances of individual validity aggregated by participant and trial did not exceed 3 points (Tukey, 1977). For ensuring that the validity did not differ between the two conditions, we compared the validity through Wilcoxon Tests. The differences did not result significant (W = 189.5, p-value = 0.44). Furthermore, we checked that the validity of individual trials did not differ between conditions through a 2-way analysis of variance (Condition, F = 0.3, p-value = 0.58; Trial, F = 1.3, p-value = 0.18).

Figure A: z-scores of the average validity aggregated by subject in long (above) and short condition (below). The plots show that the average z-scores do not exceed a value of 3.

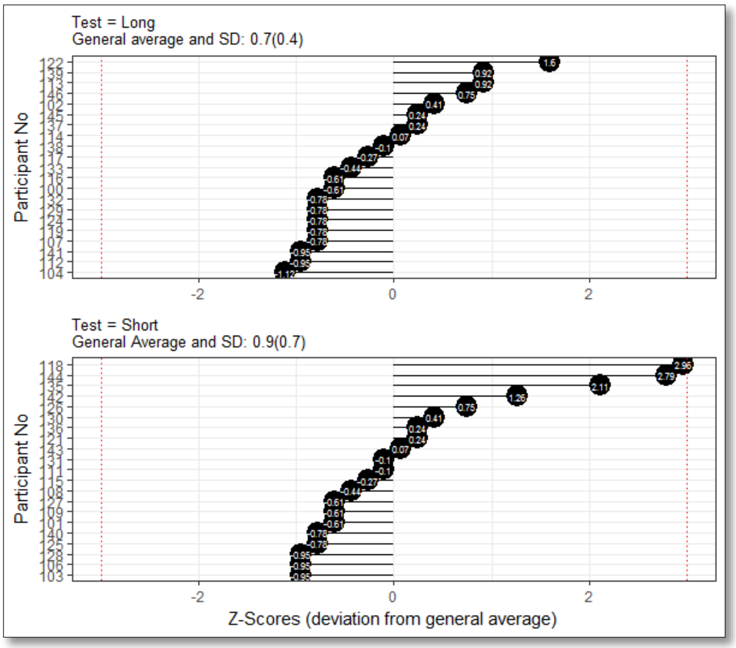
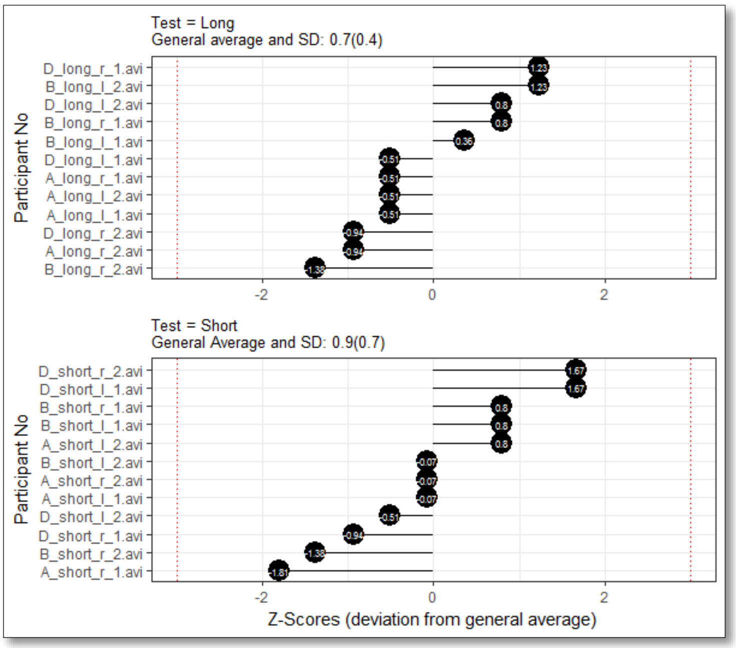


Figure B: z-scores of the average validity aggregated by trial (represented by the media name, on the y-axis) in long (above) and short condition (below). The plots show that the average z-scores do not exceed a value of 3.



Validity during the Calibration

Similarly, the following considerations aimed to ensure that the calibration was performed with the highest precision in both conditions. In the experiment, we included an additional calibration stimulus (a rolling ball moving through the corners and the center of the screen for 12 seconds; see figure C) immediately after the accomplishment of the eye-tracker calibration. The average validity during the calibration check was 0.2 (standard deviation = 0.3) in the long condition and 0.5 (standard deviation = 0.8) in the short condition. The z-scores aggregated by subject did not exceed 3 (see Figure D); the average validities were compared between the two conditions through the Wilcoxon Test that was not significant (W = 845, p-value = 0.74).

Figure C: calibration checker image (on the left), and calibration checker image with superimposed heat-map of the average fixation locations (on the right).The heat-map shows that the locations of the individual fixations were consistent among participants. The minimum deviance is explicable by the fact that the stimulus was moving.

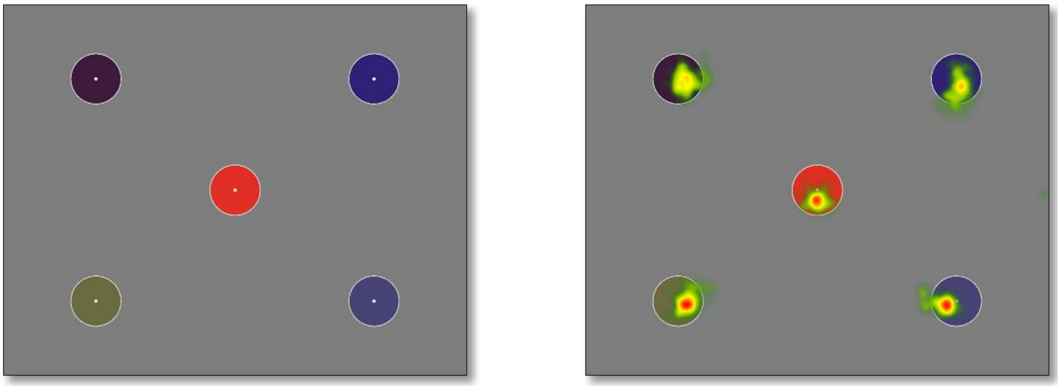
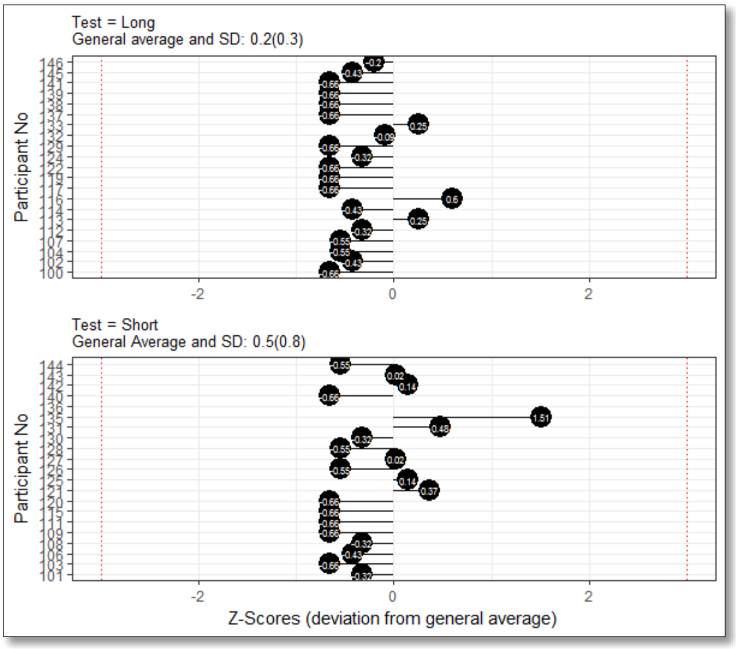


Figure D: z-scores of the average validity during the calibration check aggregated by participant in the long (above) and short condition (below). The plot shows that the average z-scores do not exceed a value of 3. One participant is missing from the second plot, as the experimenter skipped the calibration checker by mistake.



Equivalence of the Groups after the Selection

In order to ensure that the groups were still equivalent after the exclusion, we compared the participants included in the main analysis by age, SES and sex. The same tests reported at pages 32 were performed. As illustrated in table A, none of the comparisons turned out significant.

Table A: Means, standard deviations and results of the statistical tests for age, SES and sex of the participants pertaining to the final samples.

Condition	N	Age [M (sd)]	SES z-scores [M (sd)]	N females
long	15	6.68 (0.66)	0.34 (0.64)	8
short	12	6.54 (0.74)	-0.14 (0.96)	8
		W=93.5, p=0.64	W=95, p=0.19	p=0.53

Chapter 2

Are people with ASD biased to look at faces?

This study aimed to compare the state of face-orienting in young adults with and without ASD in different conditions. Considering the previous findings on infants and children, showing a comparable initial bias and a developmental decrease during childhood, we aimed to characterize face-orienting in early adulthood. An impaired face-orienting may confirm a descendent trend because of atypical development, whose consequences on visual behavior may be even more acute in young adults with ASD. The absence of a difference instead may implicate that the developmental delay is balanced by compensative mechanisms and the accumulation of experience with faces.

As we highlighted in the introduction, face-orienting is the effector of the sustained attention to the face whose duration is subjected to attentive regulation. Accordingly, longer fixations predicts face-processing difficulties in at-risk groups. Therefore, we will examine the attentive selection of social information beyond face-orienting – as measured with the average fixation duration and the proportional looking time to the face

Most of the research investigating face-orienting and sustained attention to the face focused on spontaneous exploration (free-viewing paradigms), while little is known about the specific patterns when explicit instructions are involved. However, there may be emerging patterns specific to ASD. For instance, in experiments of visual search of objects, individuals with ASD showed shorter fixations (Joseph, Keehn, Connolly, Wolfe, & Horowitz, 2009), results that has been related to faster processing after attentive selection. The opposite pattern – longer fixations – may be expected when the task involves attributing a mental state, as individuals with ASD tend to have difficulty reading expressions and intention from the expression of a face (Baron-Cohen, Campbell, Karmiloff-Smith, Grant, & Walker, 1995). Therefore, our study aimed to characterize the influence of explicit instructions that involved visual-search and the attribution of mental state on face-orienting and the sustained attention on the face.

Method

Participants

44 young adults participated in the current study (1 participant from the group with typical development was excluded for excessive blinking); 20 had atypical development, and 24 history of TD.

The participants with atypical development had a diagnosis of “High Functioning Autism” (13) or “Asperger Syndrome” (7) according to the guidelines of the DSM IV (American Psychiatric Association, 1994). The participants’ average Intelligence Quotient, as measured with the Wechsler Adult Intelligence Scale (Wechsler, 2008), was 96.11 (standard deviation = 11.6), with an average verbal sub-quotient of 100 (standard deviation = 15.6) and an average performative sub-quotient of 101 (standard deviation = 14.4). As the participants’ verbal sub-quotient lied in the normative range, we assumed that they would comprehend the verbal instructions and included all of them in the main analysis. The high percentage of correct responses of this group to the questions included in the experiment confirms the optimal reception of the instructions, as reported in the Preliminary Analysis section.

We calculated the socio-economical scores (SES) using the Four-Factor Index of Social Status (Hollingshead, 1975). In the present study, our sample represented a medium status in the Italian population (Venuti & Senese, 2007). In order to assess that the groups were comparable in terms of IQ, we collected the Raven Matrices (Raven, Raven, &

Court, 1998). The participants did not differ in terms of age (W = 228, p-value = 0.58), IQ as measured with the Raven Matrices (W = 90.5, p-value = 0.07) and SES (W = 179, p-value = 0.62). In Table 3, we report the means and standard deviations by group of age, IQ and SES.

Table 3: Mean and standard deviations across groups of Age, SES and IQ. ND = Neurodevelopment, A=Age, SES= Socio-economical Score, IQ=Intelligence Quotient, ♀ = female, N = number, M = mean, sd = Standard Deviation.

ND	A [M (sd)]	SES [M (sd)]	IQ [M (sd)]	♀ (N)
ASD	22.1 (3.8)	43.8 (14.4)	118 (10)	0
TD	22.4 (3)	42.1 (11.4)	122.4 (8.1)	8

Tools

Apparatus

We used a Tobii T120 eye-tracker (Tobii Technology, Stockholm), with a sampling rate of 60 Hz. The integrated monitor had a resolution of 1280*1024 and size of 17’’. The experiment was designed and run through the software Ogama (Vosskühler, Nordmeier, Kuchinke, & Jacobs, 2008). For collecting the participant’s answers, we used a Python script.

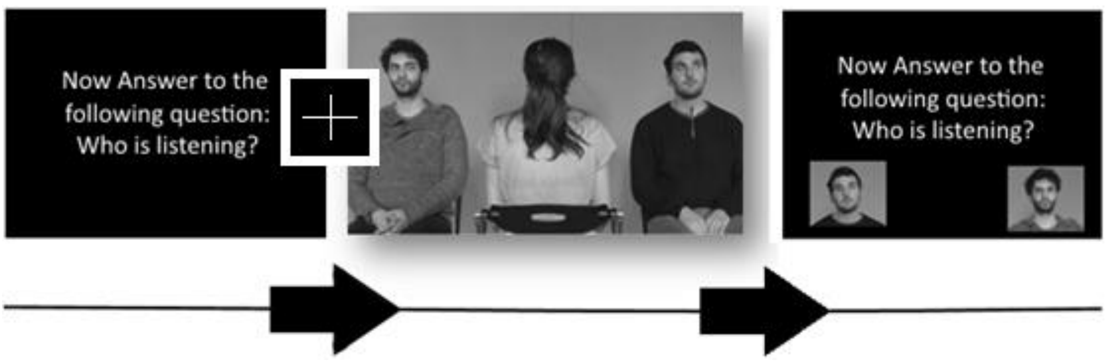
Stimuli

The stimuli consisted of 24 10-second interval videos, where three models (one central, two on the sides) seated in front of a grey wall. The central model was always a female, while the models on the sides were males/females in half of the videos. The central model had only her back visible and she pronounced a predefined sentence in Italian (i.e., “*I will go home next Tuesday. I am going to University with the whole family.*”). When the central model started to talk, the two model on the sides shifted their gazes either towards/away from the central model. One of the two facing-forward models wore a pen on his/her dress. The position of the facing-forward models, the direction of the gaze-shifts both towards and away from the central model and the position of the pen were counterbalanced across the experiment.

During each block, a 7-seconds instruction preceded and a 7-seconds answer screen followed the video. The total duration of one block (including instruction, video and answer screen) was 24 seconds. The three types of instruction are enlisted below:

- *Simply watching the video ("Now, simply watch the video"; Condition 1, or free-watching condition)*
- *Finding a (specified) object located on the body of one of the characters ("Now answer the question: Who has the pen?"; Condition 2, or visual search condition)*
- *Identifying who is listening by using gaze direction information ("Now answer the question: Who is listening?"; Condition 3, or gaze-reading condition)*

Figure 7: example of the sequence composed by instruction, fixation cross, video and answer screen.



Each instruction was repeated 8 times with a randomized order, for a total of 24 blocks per participants. Each trial starting with one of these instructions corresponded to Condition 1 (free-viewing condition), 2 (visual search condition), and 3 (gaze-reading condition).

Procedure

The participant sat in from of the eye-tracker and the keyboard in a homogeneously well-lit room. The experimenter instructed the participants to look at the screen, follow the instructions before each video and press one of the two specified keys to choose an answer when displaying the answer screen. After instructing the participant, the experimenter sat behind a curtain and monitored the participant's gaze. Before starting the experiment, the participants performed two practising blocks without recording eye movements. Subsequently, the experimenter started the 5-points calibration procedure, consisting in a red ball moving between the edges and the centre of the screen. The calibration was accepted when all the positions had been sampled (on average, no more than 2 attempts were needed for each participant).

Data Analysis

Preliminary Analysis

We preprocessed the data using the standard fixation filter of Ogama (distance threshold = 35 pixels, samples minimum value = 10). Total fixation durations were calculated within 6 predefined AOIs, (face and body of the models, central model and background), drawn on the stimuli and aggregated in two groups (faces and bodies). The percentage of correct responses from each subject was calculated and no statistically significant difference was detected (General: ASD = 87.9% (standard deviation = 12.8), TD = 88.8% (standard deviation = 12.4), W = 224, p-value = 0.7. Condition 2: ASD = 81.2% (standard deviation = 24.1), TD = 81.2% (standard deviation = 24.1), W = 230.5, p-value = 0.82. Condition 3: ASD = 88.8% (standard deviation = 16.1), TD = 85.9% (standard deviation = 20.6), W = 225.5, p-value = 0.71).

The average data loss (as measured by the output "Percentage of Samples Out of the Screen") within the duration of the movies was very low, with an average of 0.01 (standard deviation = 0.1) in the TD group and 1.6 (standard deviation = 6.5) in the ASD group. The percentage of data loss was compared through the Wilcoxon Test and did not differ between groups (W = 271, p-value = 0.36). The data loss had inter-subject minimal variation, with a minimum z-score of -0.17 and a maximum z-score of 0.08 across the two groups.

Main analysis

In order to test whether the faces would primarily attract the attention of both groups, we compared the proportion of first fixations landing on the face with chance probability (estimated as 1 divided by the total number of areas of interest) through Wilcoxon Tests. A proportion significantly above chance probability indicates a bias to shift the first fixation to the face. An equal proportion in both groups would indicate that they showed a similar effect of the face on the first fixation and that a bias to direct the attention to the face is durably preserved in adult individuals with high-functioning ASD.

Additionally, we examined two aggregated measures, the average fixation duration on the face and on the body, and the proportional looking time on face; both variables accounts for the adaptation of eye-movements to the instructions (Holmqvist et al., 2011). Furthermore, the proportional looking time accounts for idiosyncratic scanning differences (Fu, Hu, Wang, Quinn, & Lee, 2012). We predicted that the faces would distract more the participants with TD in the visual search task and that they would display a longer fixation duration on the face compared to participants with ASD. On the contrary, we anticipated that participants with TD had a gaze-processing advantage in the gaze-reading condition and would display a shorter fixation duration on the face compared to the ASD group.

Hence, we compared the average fixation durations on body and face and the proportional looking time on face between and within groups through Wilcoxon Tests. The reported comparisons have been selected through Bonferroni Correction (p-value < 0.05/N of comparisons).

Results

Proportion of first looks from centre to the face (FF%)

We selected those trials where the eye position landed on the AOI “Centre” before the onset of the first gaze shift (i.e., valid trials; average number of valid trials: ASD, Cond 1 = 6.8 (standard deviation = 1.42), Cond 2 = 6.47 (standard deviation = 1.64), Cond 3 = 6.44 (standard deviation = 1.79). TD, Cond 1 = 6.3 (standard deviation = 1.74), Cond 2 = 6.87 (standard deviation = 1.58), Cond 3 = 6.35 (standard deviation = 1.61)). Participants that displayed less than 3 valid trials were excluded from the subsequent analysis, thus resulting in a final sample of 39 (16 from the ASD group, 23 from the TD group).

We divided the total numbers of valid trials where the first fixation landed on the AOI "Face" by the total numbers of valid trials where the first fixation landed on any of the other AOIs – body, central model and background (FF%, means and standard deviations are reported in Table 4). We then compared FF% to the probability of hitting the AOI “Face” by chance (1/total N of independent AOIs = 0.2) and performed group comparisons.

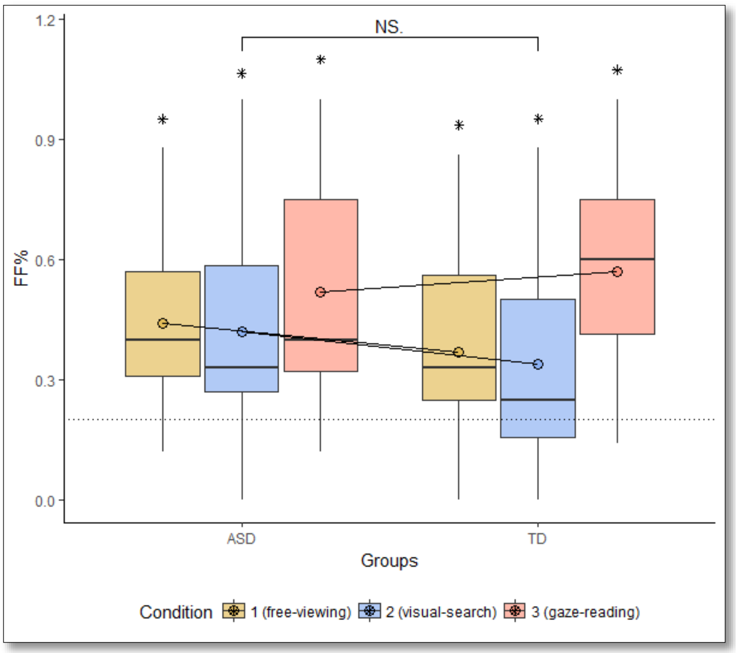
Table 4: Average proportion and standard deviations of FF%. ND = Neurodevelopment, Cond = Condition, M = Mean, sd = Standard Deviation.

ND	Cond = 1 [M (sd)]	Cond = 2 [M (sd)]	Cond = 3 [M (sd)]
ASD	0.44 (0.21)	0.42 (0.27)	0.52 (0.27)
TD	0.37 (0.27)	0.34 (0.26)	0.57 (0.23)

Multiple Wilcoxon tests revealed that FF% was above chance in all groups and conditions (Cond 1: ASD: W = 115, p-value = 0.001, TD: W = 216, p-value = 0.009; Cond 2: ASD: W = 108, p-value = 0.003; Cond 3: ASD: W = 134, p-value = 3e-04, TD: W = 272, p-value = 0.00002). The result of TD participants in Condition 2 was significant but did not resist to Bonferroni Correction.

The groups did not differ in terms of FF% across conditions (Cond 1: W = 199.5, p-value = 0.42; Cond 2: W = 209.5, p-value = 0.27; Cond 3: W = 156, p-value = 0.43). The results concerning FF% are displayed in Figure 8.

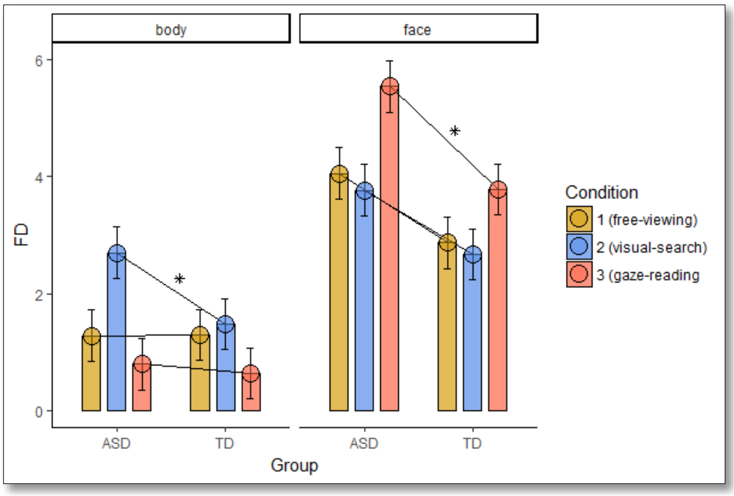
Figure 8: Average FF% across conditions and groups.



Average Fixation Duration on AOIs (FD)

FD on Body differed significantly between the groups for Condition 2 (Visual Search), with longer FD (W = 369, p-value = 0.001) in the ASD group. FD on Face was significantly different between the groups for Condition 3 (Gaze Reading), with longer FD (W = 388, p-value < 0.001) in the ASD group. We found no significant correlations between the FD and IQ level of the participants in both groups. The results are displayed in Figure 9.

Figure 9: Average FD within the two groups of AOIs, across groups and conditions.



Proportional looking time on face compared to the other AOIs (LT%)

We calculated LT% by dividing the Total Fixation Duration on Face by the Total Fixation Duration on the other AOIs. Means and standard deviations of LT% are reported in Table 5:

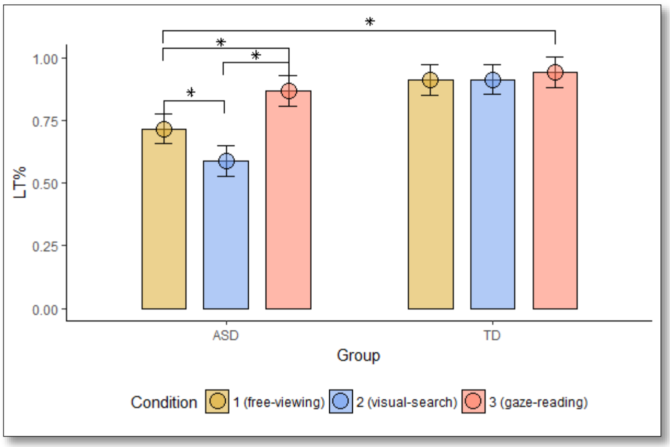
Table 5: means and standard deviations of LT% Face. ND = Neurodevelopment, Cond = Condition, M = mean, sd = Standard Deviation

ND	Cond = 1 [M (sd)]	Cond = 2 [M (sd)]	Cond = 3 [M (sd)]
ASD	0.72 (0.2)	0.59 (0.16)	0.87 (0.12)
TD	0.91 (0.15)	0.91 (0.14)	0.94 (0.10)

The groups differed in terms of LT% across conditions (Cond 1: W = 87, p-value < 0.001; Cond 2: W = 36, p-value < 0.001; Cond 3: W = 113, p-value = 0.002).

Within-group comparisons showed that LT% significantly differed across conditions in the ASD group only (ASD, Cond 1 vs Cond 2: W = 157, p-value = 0.002, Cond 1 vs Cond 3: ASD: W = 13, p-value < 0.001, Cond 2 vs Cond 3: ASD: W = 13, p-value < 0.001; TD, Cond 1 vs Cond 2: W = 34, p-value = 0.96, Cond 1 vs Cond 3: W = 9, p-value = 0.03, Cond 2 vs Cond 3: W = 8, p-value = 0.09), as shown in Figure 10.

Figure 10: Proportions of LT% on Face, compared to the other AOIs, in the three conditions.



Discussion

The first set of analysis showed that the proportion of first looks to the face was above chance level, irrespective of group and condition. This observation confirmed the integrity of face-orienting abilities in young adults with high-functioning ASD. Considering that the face-orienting bias is documented in infants at risk of ASD (Elsabbagh, Gliga, et al., 2013), is heterogeneously impaired in children with ASD (Chawarska et al., 2013), and correlates with face-processing abilities (de Klerk et al., 2014), we may conclude that face-orienting may either deteriorate in certain subgroups with severe outcome, or endure a developmental delay but possibly recover and/or establish compensative mechanisms.

The average fixation duration on the AOIs was prolonged in participants with ASD compared to controls; in particular, FD on Body was prolonged in the visual search condition and on Face in the gaze-reading condition. These observations partially sustain our initial hypotheses, as a prolonged fixation duration on the face in the group with ASD may be associated with processing difficulties, as it has been previously reported (Elsabbagh, Gliga, et al., 2013) – even though we did not observe any difference in the accuracy of the responses. Nonetheless, a diminished distractive power of the face cannot explain the longer fixation duration on the body in the visual search condition in the ASD group, as the fixation duration on the face did not differ between groups in the visual search condition. Furthermore, it is unlikely that a processing difficulty explains the difference in this latter case. A tendency to sustain the fixation on the items that the instructions had indirectly highlighted may explain both results, as the significant differences are limited to those AOIs that were relevant to the task (Body in condition 2, Face in Condition 3).

The proportional looking time on the face significantly differed between groups in all conditions. It is important to note that the participants with ASD had longer average fixation durations, compared to the participants with TD, in all conditions; nonetheless, the proportional looking time, weighted for the length of the total fixation duration of each participant, showed that the participants with ASD looked relatively less at the face in all conditions. Thus, the unequal proportional looking times on face between conditions in the ASD group explains the general difference: participants with ASD showed the minimum proportion of sustained attention to the face in the visual-search condition, and the maximum proportion in the gaze-reading condition. The proportional looking time was diminished in the free-viewing condition too, compared to the TD group. Furthermore, the proportional looking times on face did not significantly vary across conditions in the TD group. In other words, participants with ASD devoted a variable proportion of their attention to the face, depending on the instruction they were given immediately before each video. This result could be explained with participants with ASD sticking more to the task and being less distracted by the face, thus exerting a higher degree of control on eye-movements. However, proportional looking time in the free-viewing condition differed significantly between groups, indicating that they might be actually less prone to sustain the focus on the face.

Furthermore, the results of the visual search and gaze-reading condition indicate that the distribution of attention of participants with ASD, beyond face orienting, is task-dependent. Remarkably, when explicitly instructed to attend to an object (Condition 2, Visual Search), participants with ASD devoted even lesser focus to the face compared to the free-viewing condition, while proportional looking times in typically developed participants remained unvaried. We observed the same pattern in the gaze-reading condition, where participants with ASD maximized the proportional looking time on the face.

We hypothesize that, even if face orienting succeeds in a relevant context, differences in response to social signal may accentuate the differences between people with typical and atypical development, especially when attention is drown on an alternative hotspot. The proportional measure better captures this difference, as participants with ASD showed longer average fixation durations in general – even though the same pattern is recognizable with both measures.

A possible explanation is that both increased FD and task-dependent LT% on the face may be the sign of defective disengagement. Disengagement is a function of attention regulation that progressively improve during development (young infants are slow at disengaging; Atkinson, Hood, Wattam-Bell, & Braddick, 1992); individuals with ASD have difficulty in disengaging from the previous focus of attention (Elsabbagh, Fernandes, et al., 2013; Ibanez, Messinger, Newell, Lambert, & Sheskin, 2008). In the case of our study, the participants may had had trouble to disengage from the AOI brought into focus by the instruction: in other words, our result may be explained by the effect of the task, though exaggerated by the delayed disengagement of participants with ASD.

Conclusion

With this study, we aimed to investigate face-orienting abilities jointly with attention regulation. We found that the participants with ASD, as compared to a typical group, displayed prolonged visual attention to the AOIS in a relevant context and in particular, they exhibited longer task-dependent proportional looking time to the AOIs.

The results of this study implies that, when their attention is explicitly drawn to objects, persons with ASD may disregard other visual items – faces included. This fact may be problematic for people with ASD, as extrinsic events often disturb social interactions and social partners highlight external objects with gestures and utterances. Once an object captivates their attention, a particularly difficult task may arise for people with ASD, as they flounder to shift their attention back to the face, with all that this implies.

Chapter 3

Do Autistic Traits, Empathy and Anxiety influence the attention to the face in the typical population?

As we outlined in the introduction, rapid shifts and the influence of/on cognitive processing on Social Attention have been extensively studied (Emery, 2000; Itier & Batty, 2009). On the other hand, sustained attention and the influence of individual characteristics on Social Attention have been partly ignored.

With this study, we aimed to investigate the joint influence of specific individual traits (i.e., Autistic Traits, Anxiety and Empathy) on sustained attention to the face. As previous studies tested the isolated effect of these characteristics and obtained inconsistent results, we hypothesized that autistic traits, anxiety and empathy influence the attention to the face jointly. As previously mentioned, the effect of autistic traits, anxiety and empathy on attention to the face may emerge from a common background of heightened arousal, thus determining a visual avoidance of faces.

For estimating the joint effect of individual factors, we collected three questionnaires (the Autistic Quotient, the Interpersonal Reactivity Index and the Symptom Checklist-90 Revised) and performed an exploratory factorial analysis for extracting two composite scores that aggregated the three dimensions in accordance with their inter-correlation. Finally, we tested the predictive power of the composite scores on the Proportional Looking Time on Face, the weighted measure that estimates the tendency to sustain the focus of attention on the face.

Method

Participants

The sample comprised 40 young adults. Participants' characteristics are presented in Table 6. We calculated the socioeconomic status (SES) through the Four-Factor Index of Social Status (Hollingshead, 1975): our sample represented a medium status in the Italian population (M= 40.72, SD= 12.55; Venuti & Senese, 2007).

Table 6: demographic information of participants. SES > 55 indicates high socio economic status. N = number, M = mean, sd = standard deviation.

			Females	Males
	N	40	27	13
Age	M (sd)	22.22 (3.3)	21.4 (3.4)	23.9 (2.6)
SES	M (sd)	40.72 (12.55)	40.72 (12.72)	41.06 (12.99)

Tools

Apparatus

We used the Tobii T120 eye-tracker (Tobii Technology, Stockholm) and the Ogama eye-tracking software (Vosskühler, Nordmeier, Kuchinke, & Jacobs, 2008). The responses were collected through a script written in Python.

Stimuli

The videos and paradigm used in the current experiment are the same described in the previous study (Chapter 2). Hereafter, we will present a brief recapitulation of the stimuli and the experimental design.

Each trial consisted of a 10-second interval video that showed 3 persons engaged in a social interaction: 2 models (males/females in 50% of the videos) faced the viewer and stared in front of them with neutral expression. A third person (a female in all the videos) sat in the middle. After 2 seconds, the central model started to talk, pronouncing a predefined Italian sentence ("I am going home on Thursday. I will go to the University with the whole family."). The same sentence was repeated in every video. When the central model started to talk, one of the two lateral models turned her eyes to her (the listener). The other model turned her gaze away (the non-listener). One of the two models wore a pen (the object) on her body. The position (left and right) and the role of the models (listener/non-listener) were counterbalanced.

Each block lasted 24 seconds and consisted of 3 segments: instruction (7 seconds), video, answer screen (7 seconds). The instructions, displayed at the beginning of each block, were:

1) "*Now, simply watch the video*."

2) *"Now answer to the question: Who has the pen?"*

3) *"Now answer to the question: Who is listening?"*

Each trial starting with one of these instructions corresponded to Condition 1 (free-viewing condition), 2 (visual search condition), 3 (gaze-reading condition). Each instruction was repeated 8 times with a randomized order, for a total of 24 trials.

Questionnaires

Autistic Quotient

The Autistic Quotient (AQ) (Baron-Cohen et al., 2001) is a self-administered questionnaire that quantifies autistic traits in individuals with normative cognitive level. The questionnaire has demonstrated a good internal consistency (Baron-Cohen et al., 2001), confirmed in the present study with Cronbach's alpha .80.

Interpersonal Reactivity Index

The Interpersonal Reactivity Index (IRI) (Davis, 1983) is a self-reported measure containing 28 items to assess empathy. The measure has 4 subscales: the Fantasy Scale (extent to which individuals identify with fictional characters), Perspective Taking (tendency of adopting the psychological point of view of others), Empathic Concern (other-oriented feelings of sympathy), Personal Distress (self-oriented feelings of personal anxiety in interpersonal settings). Good internal consistency has been reported (Davis, 1980; De Corte et al., 2007); for the present study, it ranged from .74 to .85 across the scales.

Symptom Checklist-90 Revised

The Symptom Checklist-90 Revised (SCL-90-R) (Derogatis, Unger, Derogatis, & Unger, 2010) is a self-reported questionnaire screening for a broad range of symptoms. In the present study, we considered the Anxiety subscale. The scales demonstrated good internal consistency (Derogatis et al., 2010; Sarno, Preti, Prunas, & Madeddu, 2011); for the present study, the internal consistency of the Anxiety subscale was .89.

Procedure

The experiment took place in a calm room, with diffuse lighting. Before the experimental session, the participant read written instructions on the screen (30 seconds) and performed two training trials without recording the eye-movements. After a successful calibration, the experimenter started the experiment and sat behind a curtain for the rest of the session. As mentioned before, the experiment consisted of 24 blocks containing the sequence: ‘Instruction, Video, Answer screen’. During the last segment, the participant pressed one of two keys to give his/her answer. After the end of the experimental session, the participants completed the 4 questionnaires. An example of the experiment stream is represented in Figure 11.

Figure 11: example of the stream of the experiment.

Data analysis

Preliminary Analysis

We pre-processed the raw eye-tracking data through the software Ogama, with the same filter settings of the previous experiment. Complete fixation duration was calculated within predefined AOIs (central model, face and body) and background. The high accuracy of responses given through the keyboard confirmed that the participants understood the task and payed sufficient attention to the scene (General Accuracy: M = 97%, SD = 6.77%; M = 95.5%, SD = 9.76 in condition 2; M = 97%, SD = 7.96 in condition 3). The estimate of samples falling out of the monitor was very low, with an average of 0.06 (standard deviation = 0.2).

Main Analysis

We calculated the Proportional Looking Time on Face (LT%) by dividing the Total Looking Time on Face by the sum of Total Looking Time on any other AOIs plus the Background. We assumed that the Proportional Looking Time would estimate the attentive selection of the face while correcting for idiosyncratic differences in the scanning patterns. In order to detect the latent factors constituted by the correlated questionnaires scores, we performed a Maximum Likelihood Factor Analysis of the AQ, the subscales of

IRI (EC, FS, PD and PT) and the Anxiety subscale of SCL.90-R (ANX). After detecting the latent factors, we calculated the composite scores with the regressive method.

To evaluate our initial hypotheses, we performed a mixed model assuming the experimental condition, the composite Factor Scores, and Sex as conditional factors on the Proportional Looking Time. Afterwards, we tested the model through an analysis of Co-Variance.

Results

Proportional Looking Time on Face (%LT) and exploratory factor analysis

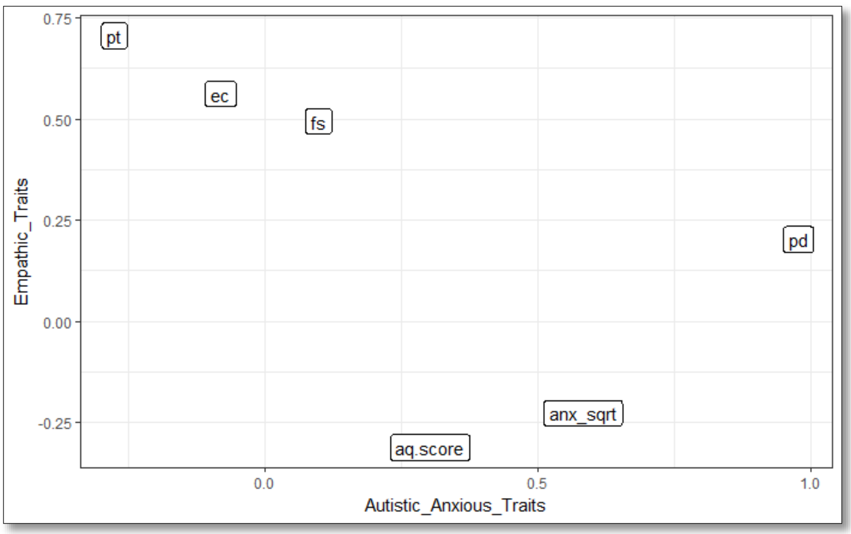
LT% on Face across conditions resulted normally distributed (W = 0.98, p-value = 0.28. Condition 1, free-viewing: M= 0.34, sd= 0.16. Condition 2, visual search: M= 0.38, sd= 0.15. Condition 3, gaze-reading: M= 0.45, sd= 0.25).

We performed the Shapiro Wilk Tests of Normality on the scores of the questionnaires, that resulted normally distributed too (AQ: p-value = 0.42; EC: p-value = 0.32; FS p-value = 0.63; PD p-value = 0.08; PT p-value = 0.57; ANX p-value = 0.15).

We inspected visually the linear relationships between the variables – shown in the Additional Material together with the correlation coefficients. We tested sampling adequacy through the Bartlett Test (χ^2 = 40; p-value = 0.0004) and Keiser Meyer Olkin Test (Individual Scores: AQ = 0.75, EC = 0.6, FS = 0.44, PD = 0.5, PT = 0.6; overall score = 0.6).

We performed a Maximum Likelihood Exploratory Factor Analysis, that is indicated for normally distributed variables (DiStefano & Zhu, 2009), with the Promax rotation method for detecting 2 Factors. Variables loadings illustrate the reciprocal correlation and contribution of the scores to the Factor; a loading above 0.3 is considered significant (Winter, Dodou, & Wieringa, 2009). AQ, PD and ANX scores had significant loadings on Factor 1 (AQ = 0.32, PD = 0.98, ANX = 0.58), whereas EC, FS and PT had significant loadings on Factor 2 (EC = 0.56, FS = 0.49, PT = 0.71). The signs of the weights signals the direction of the correlation (positive or negative). In this case, the significant weights of Factor 1 and 2 have positive sign – meaning that the variables grew to the same direction. The loadings suggested that the factor differ qualitatively. PD and ANX, that illustrate the participant's level of anxiety, and AQ, that measures Autistic Traits, contributed to Factor 1. On the other hand, EC, FS and PT, that connoted empathetic characteristics, significantly correlated with Factor 2. Given the composition of the factors, we adopted the following labels: Autistic-Anxious Attributes (Factor 1) and Empathic Attributes (Factor 2). A graphical representation of the composition of Factor 1 and 2 is provided in Figure 12.

Figure 12: graphical representation of the grouping factors, illustrating the loadings of the individual variables (correlation coefficients on the x ad y-axis). .



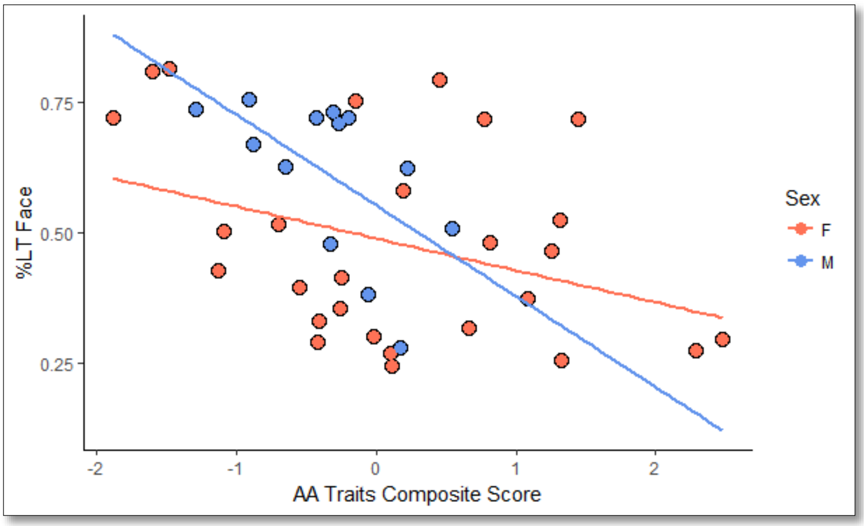
The model resulted statistically acceptable, with a Chi-square statistic of 3.83 on 4 degrees of freedom and a p-value of 0.43. Cronbach's alpha standardized values corresponded to 0.63 for Factor 1 and 0.6 for Factor 2. We calculated composite scores for Factor 1 and 2 for each participant, based on the Regression Method.

Linear Mixed Model and Analysis of Variance (Type III test)

We designed a linear mixed model regressing the proportional looking time to the face on the novel scores of the Autistic-Anxious Attributes and Empathic Attributes calculated for each participant and the experimental condition, assuming sex as a covariate.

The model indicated that the fixed effects due to the Autistic-Anxious Attributes (t = -2.59) and Sex (t = -3.71) were significant. The Analysis of Variance of type III confirmed a significant effect of Autistic-Anxious Attributes (χ^2 = 5.28, p-value = 0.02) and Sex (χ^2 = 13.8, p-value = 0.0001). The relationship between LT% on Face and Anxious-Autistic Attributes is shown in Figure 13.

Figure 13: the plot illustrates the negative relationship between Proportional Looking Time (LT%) and the Autistic Anxious Attributes (AA Traits Composite Score) in female and male participants.



Discussion

We hypothesized that the conjunction of autistic and anxious symptoms influences the attention to the face – in other words, that, the level of anxiety may play a role in persons with high scores on the AQ. In our study, we found that variables measuring anxiety and autistic traits contributed with a positive weight to a unique factor. The factor that we labelled Autistic-Anxious Attributes negatively influenced Social Attention: the higher the autistic-anxious attributes were, the lower the proportion of time spent fixating the face was. The variations of Proportional Looking time was not attributable to the different instructions, as the effect of the condition did not result significant. This finding gives a new light to the influence of autistic traits on Social Attention. First, previous studies on autistic traits may have failed in finding an association because they did not take into account the anxious symptoms of the participants. In our case, we did not only consider them, but we measured them in conjunction with the autistic traits with the factor analysis. Our finding suggests that anxiety is shaping attention to the face where autistic traits are high.

As we mentioned in the introduction, there is a theory of autism proposing that the aversive symptoms may arise from an excessive arousal level triggered by social stimuli (Dalton, Nacewicz, Alexander, & Davidson, 2007). Our result supports this hypothesis, by showing that the amount of autistic traits plus anxiety negatively affect the amount of attention devoted to the face.

We found also the effect of sex as a covariate. Males and females show different fixation patterns and face processing abilities (female adults display shorter fixations and better recognitions skills, Rennels & Cummings, 2013). In our study, females displayed smaller Proportional Looking on face in all conditions, fact that may reflect the association between fixation length and processing advantage.

One limitation of this study is the fact that the results of the exploratory factor analysis with a small sample size may be “sample specific” (Winter et al., 2009). However, we can assume that the sample size is adequate for the current exploratory analysis, based on the good amplitude of the R^2 relative to the mixed model (0.96), and the power achieved with a moderate effect size (~0.8 and an effect size of 0.3). Furthermore, the factor analysis with small sample sizes has not been discouraged, as long as the rationale of the research lies on strong theoretical considerations and has the potential to clear out the way to renovating hypotheses (Winter et al., 2009), as we believe this is the case.

Conclusion

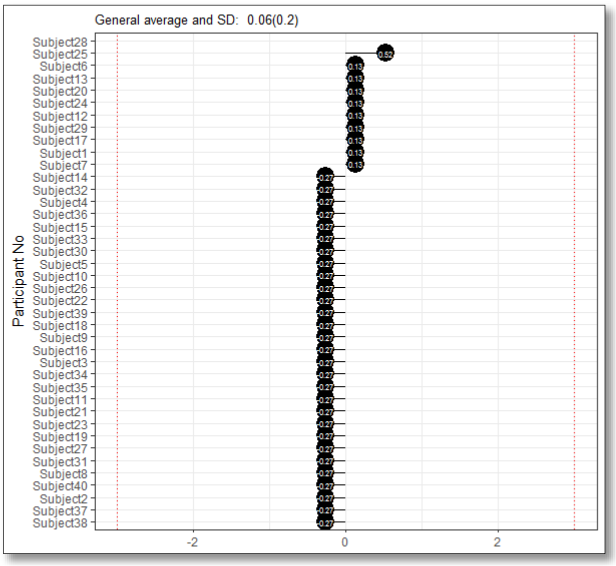
The study explored the connection between the Proportional Looking Time to the face and the composite scores obtained through the stratification of Autistic Traits, empathy and anxiety indicators. In fact, we aimed to consider these factors in concert, as their combined effect had not been investigated before. The result highlights that Autistic Traits, personal distress (the self-centred expression of empathy occurring when witnessing others in distress) and anxiety jointly influence the sustained focus on the face. We believe that this finding encourages future studies on Social Attention to regard personal distress and anxious symptoms as crucial factors, and to explore their effect concomitantly with Autistic Traits.

Additional Material

Data Quality

The plot illustrates the z-scores of the percentage of samples fallen outside of the monitor across the videos, per participant:

Figure A: Z-scores of the percentage of samples falling out of the monitor across the videos per participant.



Correlations between the questionnaire scores

Linear relationships (Figure B) and correlations coefficients of the scores (AQ, subscales of IRI, anxiety score of the SCL) (Figure C).

Figure B: linear relationships between the questionnaires' scores; aq = Autistic Quotient, ec = Empatic Concern, fs = Fantasy Score, pd = Personal Distress, pt = Perspective Taking, anx = Anxiety Score.

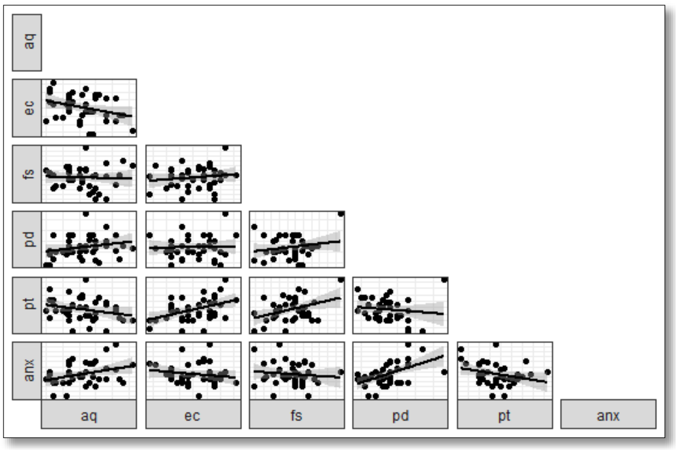
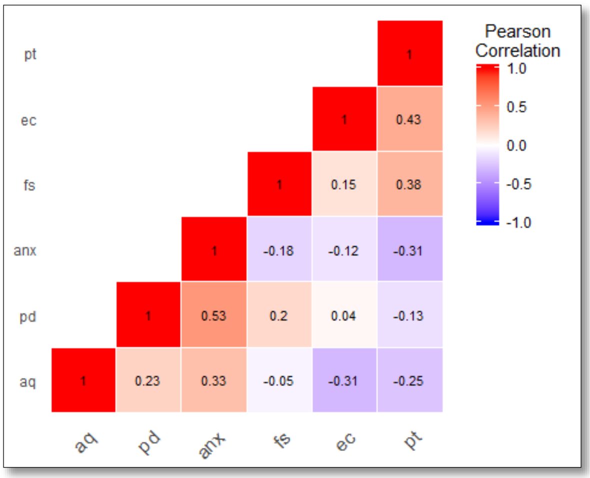


Figure C: Pearson correlation coefficients between the questionnaires' scores; aq = Autistic Quotient, ec = Empatic Concern, fs = Fantasy Score, pd = Personal Distress, pt = Perspective Taking, anx = Anxiety Score.



Conclusions and Future Directions

The Social Gaze, definition that encompasses face-orienting, gaze-following and sustained attention to the face, is a crucial behaviour that develops during the first year of life and contributes to the emergence of complex social behaviours, such as Joint Attention and language. This thesis addressed questions regarding the factors influencing face-orienting, sustained attention to the face and gaze-following in typical and atypical development. We focused on the method of eye-tracking, the gold standard for the study of eye-movements and social attention, that supported us in investigating our questions and producing useful evidence. The following paragraphs will address the theoretical and practical implications of our findings, and suggest future developments of these lines of research.

1. What is the impact of face presentation time on gaze-following?

By manipulating face-presentation time in the first study, we tested the prediction that infants follow gaze more frequently when they are provided with time to habituate to the face. Nonetheless, the variable estimating the tendency to follow gaze, the Difference Score, resulted above chance in the Short Condition, and the participants assigned to the Short Condition obtained higher Difference Scores. Our result contrasts one of the main predictions of the PLeASES Theory – that a domain-general process, habituation, is beneficial for gaze-following. Instead, this result suggests that the temporal proximity between ostensive cues and gaze cues is substantially more important, as predicted by the Natural Pedagogy hypothesis. This hypothesis has been recently criticized, mainly for its claim that the effect of eye-contact on an infant’s subsequent actions is unique and not reproducible when an adult performs alternative, attention-grabbing actions (Gredebäck, Astor, & Fawcett, 2018; Szufnarowska, Rohlfing, Fawcett, & Gredebäck, 2014).

However, the theory might have captured one of the major determinants of early social interactions: time contingency, represented in this experiment by the temporal link between the ostensive and the gaze cues.

We believe that our result supports this view: it is possible that an infant expects the adult "to do something" after she engaged her attention and established a link with the observer. As we will discuss shortly, the role of time contingency is not new to developmental science, even though the perspective of Natural Pedagogy might challenge the long-lasting view on time contingency.

The role of Time Contingency

The curious thing is that, by its own traditional definition, contingency indicates "the absence of certainty in events" and "the absence of necessity" as the condition for a certain behaviour (Oxford English Dictionary, 2015). Accordingly, the patterns of contingent responsivity during early interactions have been historically linked to an infant's unique experiences within the infant-maternal dyad (Kaye & Fogel, 1980). This line of research showed that infants floundered when confronted with a person less familiar than their mother during face-to-face interactions (Bigelow & Rochat, 2006). In this context, the idea that infants recognize and respond to specific patterns of time contingency as they are exposed and learn the caregiver's interactive style was conceived: to this view, this adaptation serves the purposes of filial attachment and emotional attunement (Csibra & Gergely, 2006). By contrast, Natural Pedagogy describes the sensitivity to contingency as a "genetic adaptation" (Heyes, 2016, p. 283), constrained by evolutionary pressure, served by an amodal sensitiveness – "not dependent on the presence of any other social cues, such as faces or human voice, or on the communicative nature of the behaviour" (Deligianni, Senju, Gergely, & Csibra, 2011, p. 6). Therefore, if the conception of Natural Pedagogy on the developmental origins of gaze-following was to be accepted, the field would be challenged with the radical revision of the notion of time contingency.

A conclusive evaluation of the developmental origins of one of the major determinants of the earliest human interactions is missing so far. The mentioned studies involved infants of different ages and in different situations, with younger infants examined in face-to-face interactions and older infants involved in the classic gaze-following paradigm, limiting the possibility of comparison. Nonetheless, Johnson et al. (2008) raised an interesting hypothesis about "the possibility of a parallel set of less well-studied abilities for recognizing intentional behaviour" (p. 35). The researchers proposed that infants might be equipped with complementary abilities that are "not grounded in personal experience" (p. 35). In other words, they proposed that different mechanisms might be at work during when an infant is confronted with a familiar or unfamiliar social partner. Longitudinal studies, considering close and more distant social exchanges, might clarify what view is closer to the reality of facts, even though a developmental change and/or distinct mechanisms are not to exclude.

The time of presentation of the face (one traditional and one experimental explanation)

None of these aforementioned studies characterized contingency in terms of timing: our study suggests that, in the absence of a close sequence, the familiar eye-contact and infant-directed speech do not function as usual. Then why a longer face presentation time elicited more early, and misled, gaze shifts?

A longer face presentation time might facilitate habituation and disengagement after all. Yet, an anticipated disengagement might not be the best option in this situation and at this stage of development. Infants younger than 12 months have limited processing abilities of diverted head angles (Farroni et al., 2006), and often confound gaze information with head and motion cues (Farroni et al., 2000). Therefore, a long face presentation time before the cue may have paradoxically shorten the time available for the processing of gaze during the cue, and eventually disrupted gaze-following. This explanation is in line with the view that connects infants' early social abilities with their cognitive and oculomotor capability, as first proposed in their seminal work by Butterworth and Jarrett (1991).

While the authors' original idea that the different patterns of expression of gaze-following are solely determined by an infant's brain maturation is outdated, a more recent account – the Dynamical System theory (Smith & Thelen, 2003) – introduced the concept that both an infant's intrinsic characteristics and the extrinsic features of the environment interact in real-time, with the momentary behaviour as an outcome. Applying this vision to our experiment needs a complete reformulation of the assumptions and research question.

First, we may assume that all the infants involved in the experiment were able to follow gaze in situations that are more similar to the short condition, as they did not differ in terms of age, social status and sex. However, the infants that were confronted with a longer face presentation time were misled. Therefore, it may be assumed that their response depended on the specific task, rather than on a cognitive limitation (what did infants assigned to the short condition learn about gaze that infants in the long condition did not?). The theory prescribes not to answer with a single, specific cause (such as inappropriate gaze processing, or sensitivity to time contingency), but with an explanation that encompasses several situations. The infant might have not be able to solve the task – interacting with a person that engages in a prolonged, frontal exchange of looks – and responded randomly. According to a dynamic system approach, we could hypothesize that the infants may have not yet developed the ability of holding a referential expectation for longer periods when they engage with a silent, facing-forward adult. This ability may arise when this situation starts naturally occurring in an infant's everyday life: for instance, when she starts to talk and produce sentences – and the adult holds still waiting for a hint. In this case, neither the universal sensitivity to contingency nor the progressive development of gaze processing abilities would explain the result, but the fact that the infants were preverbal! The unpredicted outcome of this consideration would be that the major correlate of gaze-following with a long face presentation time would be an infant's productive verbal ability.

Unfortunately, the dynamic system theory has received little attention, and limited evidence is available in favour or not of its predictions. The application of this perspective to our results is intriguing (and provocative), and remains to be tested.

2. Are people with ASD biased to look at faces? Are there any differences between atypical and typical development in the attentive selection of socially relevant stimuli beyond face-orienting?

The second study shows that high-functioning people with ASD vary their sustained attention to the face, differently from typically developed peers. Basic deficits in the sensitiveness to face configuration could not explain the latter finding, since face orienting was intact. The finding on proportional looking time suggested that the regulation of attention and its interaction with specific social-orienting abilities might be impaired in ASD.

When the person with ASD is engaged in the visual exploration of a social stimulus, data indicate that sustained attention is shorter, compared to the span of a person with typical development (Sacrey, Armstrong, Bryson, & Zwaigenbaum, 2014). Therefore, it has been suggested that, in natural interactions, a person with ASD may disengage too early from the main source of social cues – the face. The diminished proportional looking time in the free-viewing condition supports this interpretation; nonetheless, explicitly drawing the attention to the face equalized the proportional looking time to the face in the two groups. Furthermore, either defective disengagement or difficult processing backfires, as the average fixation duration of the ASD group is 1.5 seconds longer than the average fixation duration of the TD group.

Our analysis further extends the observation that, when engaged to objects, people with ASD significantly sustain the fixation for longer periods. Previous research highlighted that this is the case for objects of high interest for persons with ASD, such as cars and trains (South, Ozonoff, & McMahon, 2005); in our study, the object was not particularly interesting but the instructions recreated the same output. Therefore, our result indicates that artificially drawing attentions on objects significantly decreases the attention to the source of social information: this situation may be recreated in interactive contexts, where the social partner continuously draws the attention to the objects of the environment. The clear implication is that, once the attention is redirected, it may be difficult to re-engage; basic patterns of behaviour during triadic interactions, such as gaze alternation during episodes of Joint Attention, may be particularly challenging to obtain.

It has been suggested that, for a successful interaction, a person with ASD needs more time for allowing the delayed disengagement from the previous focus of attention (Sacrey et al., 2014), and additional measures for catching the glimpse of social cues and redirect his/her attention to the referent of the exchange are necessary (Leekam et al., 1998; Thorup et al., 2016). The third moment too, when the shared attention is finally obtained, may be problematic, as the person may lock his/her attention on that spot. Therefore, the focus of interventions should include the facilitation of the disengagement from the target object of the interaction too. Playing with the face may help doing the trick: let us not forget that this same study confirmed that persons with ASD show a strong bias for shifting their attention to the face. At the same time, the task-dependent modulation of looking times suggests that persons with ASD may be particularly strong in their top-down ability of regulating the attention, whereas defective disengagement may render exogenous, unexpected events less effective. A good suggestion for future research would be directly comparing the two modalities: a clear difference may be a useful source of information for structuring successful interventions.

3. Do Autistic Traits, Empathy and Anxiety influence the attention to the face in the typical population?

A joint effect of Autistic Traits, Anxiety and Personal Distress emerged, drawing attention on the coaction of specific characteristics that often coexist in the same persons. Such characteristics share the influence on the attention to the face, and may affect together Social Attention in general.

This study suggests that a system of intrinsic characteristics, apparently pertaining to different dimensions, might interact and jointly influence the behavioural outcome. In this case, autistic traits, anxiety symptoms and personal distress concurred in influencing the proportional looking time on the faces. This finding highlights the role of high levels of personal distress among the dimensions of empathy, as it was the only sub-score entailed in the prediction. Traits of anxiety and personal distress are scarcely taken into account in studies on autistic traits and ASD, and more often as a comorbidity rather than an integral part of the clinical picture. The question remains about the causes of the association between autistic traits, personal distress and anxiety. It has been suggested that the relationship may be actually mediated by the experiences of the individual with high autistic traits: one study found that difficult social problem-solving and teasing experiences mediated the association between autistic traits and symptoms of anxiety (Rosbrook & Whittingham, 2010). On the other hand, a large study on the relatives of persons with ASD found that they showed more autistic traits as well as anxious traits compared to the controls (Murphy et al., 2000). Therefore, the genetic predisposition might partly account for a higher risk of developing anxiety and personal distress. Anyway, the two conditions are not mutually exclusive. Our finding further justifies that the focus of interventions should include regulating the anxious state of the individual, and acting on the possible environmental triggers, such as poor social-problem solving and teasing (Rosbrook & Whittingham, 2010).

As a whole, our results indicate that several factors, pertaining to distinct dimensions, influence the social gaze. From the theoretical point of view, this notion suggests that the development of the social gaze works as a system, where characteristics of the observer and of the environment interact for responding to a specific task and at a specific moment of development. This is the case of temporal contingency and disengagement, whose relationship with the social gaze may even be non-linear (i.e., changes over time). On the other hand, the results indicate that research and interventions need attention to multiple causes of malfunctioning; for instance, persons suffering of social isolation because of high levels of autistic traits might be heavily affected by concurrent anxiety and personal distress. Furthermore, a singular deficit might have a cascade effect on several stages of interactions: none of these phases should be ignored when an intervention is planned.

One limitation of this work is that, as it is common in this research field, our results lay at the behavioural level: it is to be hoped that deeper and more specific levels of analysis will become widespread. It is encouraging to think that eye-tracking rapidly evolved and spread out in 10 years only, providing new evidence and giving sparks to new ideas. We believe that with the good clues provided by accurate observations and creativity, research will progressively answer the more complicated questions concerning the foundations of behavioural differences in brain development and activity. We hope that the current thesis can contribute to the implementation of subsequent levels of analysis for unfolding the possible stages of development.

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