The Effect of Eye Contact on Arousal and Attention
A psychophysiological perspective
TERHI M. HELMINEN

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ACADEMIC DISSERTATION
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ABSTRACT

Eye gaze plays a special role in human interaction by carrying nonverbal information about others’ focus of attention, intentions, and mental states. In the present thesis, the effects of direct gaze on a perceiver’s arousal and attentional responses, indexed by autonomic nervous system responses, were investigated in typically developing adults (Study I and II) and in young children with and without autism spectrum disorders (ASD) (Study III).

In Study I, it was shown that the direct gaze of a live person causes elevated arousal responses, measured with skin conductance, when compared with averted gaze or closed eyes. Enhanced arousal responses to direct gaze were observed irrespective of the length of the direct gaze, overruling previous speculations that enhanced arousal responses would be restricted to prolonged eye contact. In addition, enhanced arousal responses were found irrespective of individual differences in personality. Instead, individual differences in emotional stability were found to affect subjective evaluations of approach-avoidance tendency in response to direct gaze.

In Study II, it was shown that direct gaze (vs. downcast gaze) had an effect on performance in a story recall task, and this effect was partially mediated by arousal. The effect of arousal on performance was negative. However, the arousal-mediated process was paralleled by another process that positively affected performance. This process was presumably related to effort allocation and motivation. The effects of participants’ belief of being seen by the storyteller on performance and arousal were also investigated, but none were found.

Finally, according to the results of Study III, children with ASD did not respond to direct (vs. averted) gaze with an enhanced physiological orientation response, measured with heart rate deceleration, whereas their typically developing and developmentally delayed peers did. The results indicate that a reason for reduced eye contact behaviour in ASD might be related to omitting direct gaze as it is not a socially salient signal for them.

Altogether, the present studies showed that people respond to direct gaze with enhanced autonomic arousal, and arousal partially mediates the effect of direct gaze on memory performance. In addition, autonomic nervous system responses were used as a means to broaden the understanding of the atypical eye contact behaviour of children with ASD.
TIIVISTELMÄ

Toisen henkilön katseen suunnan havaitsemisella on keskeinen merkitys sosiaalisessa vuorovaikutuksessa. Tässä väitöskirjassa tarkasteltiin suoran katseen vaikutuksia havaitsijan vireystilaan ja tarkkaavaisuuteen autonomisen hermoston mittareiden avulla aikuisilla sekä autismikirjon lapsilla ja heidän tavanomaisesti kehittyneillä ja kehitysviiveisillä ikätovereillaan.

Väitöskirjan ensimmäinen tutkimuskysymys käsitteli sitä, saako katsekontakti (verrattuna sivulle käännetyn katseeseen tai suljetuhiin silmiin) aikaan voimistuneita, vireystilan muutoksista kertovia ihon sähkönjohtavuuden vasteita. Enimmäisen osatutkimuksen tulosten perusteella näin oli, riippumatta katsekontaktin kestosta tai havaitsijan persoonallisuuden piirteistä. Emotio naalien tasapainoisuuden piirteillä huomattiin kuitenkin olevan vaikutusta siihen, olko osallistujilla taipumus välttää vai lähestyä henkilöä, joka katsoi heitä silmiin.

Aiemmissa tutkimuksissa on havaittu, että suoralla katseella on vaikutusta havaitsemaan suoriutumiseen kognitiivisissa tehtävissä. Väitöskirjan toinen osatutkimus näytti, että suoran katseen herättämä autonominen virittyneisyys välittää osittain suoran katseen vaikutusta kuullun tarinan muistamiseen. Tässä tutkimuksessa virittyneisyyden vaikutus suoriutumiseen oli negatiivinen. Virittyneisyyden rinnalla suoran katseen vaikutusta välitti kuitenkin myös toinen, positiivisesti suoriutumiseen vaikuttava prosessi, joka oletettavasti liittyi motivaatioon ja ponnisteluun tehtävissä. Tutkimuksessa tarkasteltiin lisäksi tietoisuutta nähdyksi tulemisesta, ja sen vaikutusta autonomiseen virittyneisyyteen ja kognitiiviseen suoriutumiseen, mutta tämän osalta merkitseviä tuloksia ei löydetty.

Kolmannessa osatutkimuksessa tutkittiin sitä, herättääkö suora katse (verrattuna käännettyyn katseeseen) voimistuneen sydämen sykkeen orientaatioreaktion autismikirjon lapsilla sekä heidän ikätovereillaan. Tulosten perusteella tavanomaisesti kehittyneet lapset ja kehitysviiveiset lapset reagoivat suoraan katseeseen voimistuneella orientaatioreaktiolla, mutta autismikirjon lapsilla tätä ei havaittu. Tulokset antavat tukea oletukselle, jonka mukaan autismikirjon lasten vähäinen katsekontaktin käyttö johtuu ainakin osittain siitä, että suora katse ei kiinnitä heidän tarkkaavaisuuttaan tavanomaisella tavalla. Tämä voi johtaa suoran katseen välittämien signaalien ja esimerkiksi vuorovaikutusaloitteiden huomioittajättämiseen.
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LIST OF ORIGINAL PUBLICATIONS

This dissertation consists of the three following publications, which will be referred to in the text by their Roman numerals I – III.


1 INTRODUCTION

‘Under optimal conditions of interpersonal encounter, the gaze of the other may be experienced as streaming into my whole being - I am filled out and irradiated by it’ (Heron, 1970). This quotation from Heron (1970) describes the power of gaze directed towards another individual in interaction between humans. Most of us have experienced situations where you suddenly get a feeling of being looked at by someone, and you quickly spot the person who is looking at you in your surroundings. When your eyes meet the other’s eyes, you might experience something like what Heron described: Something ‘streaming into your whole being’, affecting your thoughts, emotions, and bodily reactions. You might be asking yourself, ‘Why is he looking at me, what is he up to?’ These thoughts are accompanied with emotional and psychophysiological reactions that prepare you to act according to what the other’s initiation of interaction requires.

In this thesis, my aim is to expand the understanding of the role of eye contact in social interaction. Eye contact is a situation where two individuals are looking directly into each other’s eyes. Although eye contact is the core interest of this thesis, the concept of direct gaze will be often used to refer to a situation where a picture’s or live person’s eyes are directed towards a perceiver.

Previous research has shown that humans have a neural network that is specialized in processing information of others’ gaze directions, and parts of that network respond to direct gaze with enhanced activation (Nummenmaa & Calder, 2009; Senju & Johnson, 2009a). This enhanced activation is seen both at the level of the central nervous system and at the level of the autonomic nervous system. Here, I will focus on the responses of the autonomic nervous system, that is, on skin conductance (SCR) and heart rate (HR) responses, which are known to be related to arousal and attentional processes. The dissertation starts by investigating whether and in which conditions perceived direct gaze affects the autonomic arousal of a perceiver. Next, I will examine the function of these reactions by exploring their effects on a perceiver’s memory performance. Finally, the autonomic reactions to gaze stimuli are used as a means to expand the understanding of atypical eye contact behaviour in young children with autism spectrum disorder (ASD).
Before describing the present studies in further detail, I will review what is previously known about the way we respond to direct gaze and then focus on arousal and attentional responses. Subsequently, the focus will be shifted to what is previously known about the effects of direct gaze on cognitive performance and memory processes. Finally, the atypical development of eye contact behaviour and responses of the nervous system to direct gaze in ASD will be described.

### 1.1 Eye contact in social information processing

Eye gaze carries important information about another person’s focus of attention, emotional and mental states, and intentions (cf. Itier & Batty, 2009; Kleinke, 1986). Direct gaze signals another person’s potential interest for social interaction. A person’s intentions might vary between friendly or aggressive, but nevertheless, direct gaze is thought to signal approach-related motivation (Adams & Kleck, 2003), which is also found to be reflected in a perceiver’s motivational brain responses (Hietanen, Leppänen, Peltola, Linna-aho, & Ruuhiala, 2008). With eye contact, two persons share emotions and build a connection between themselves. Paying attention to a person who is looking at oneself is relevant for successful social encounters, for forming social relationships, and even for one’s well-being in general. The perception of direct gaze triggers self-referential processing that leads, for example, to the enhanced processing of incoming information, enhancement of self-awareness, and increased prosocial behaviour (Conty, George, & Hietanen, 2016). In other words, eye contact plays a special role in social information processing.

The eye region, together with the mouth area, is the key area where people tend to pay attention while looking at faces, as shown by studies using eye tracking technology (e.g. Klin, Jones, Schultz, Volkmar, & Cohen, 2002; Pelphrey et al., 2002). A bias for looking at others’ faces, especially the eyes, emerges early in human development. Few-days-old babies track face-like patterns longer than non-face patterns (Goren, Sarty & Wu, 1975; Johnson, Dziurawiec, Ellis, & Morton, 1991; Mondloch et al., 1999; Valenza, Simion, Cassia, & Umiltà, 1996) and prefer faces with open eyes over closed eyes (Batki, Baron-Cohen, Wheelwright, Connelan, & Ahluwalia, 2000). Neonates are able to differentiate another person’s direct gaze from averted gaze, and orient more often and look longer at faces with direct gaze than faces with averted gaze (Farroni, Csibra, Simion, & Johnson, 2002). This tendency to pay attention to faces, and especially to direct gaze,
presumably forms a foundation for their emerging skills of social interaction (Jones, Gliga, Bedford, Charman, & Johnson, 2014).

Neuroimaging studies have shown that there exists a distributed neural network that is sensitive to another person’s gaze direction (for reviews, see Itier & Batty, 2009; Nummenmaa & Calder, 2009; Senju & Johnson, 2009a). This so-called social brain network includes both cortical and subcortical structures that are known to be involved in face perception (the fusiform gyrus, superior temporal sulcus, and gyrus in temporal areas), attentional processes (the inferior and superior parietal lobules and frontal eye field), and emotion processing and social cognition (the amygdala and medial prefrontal cortex). These cortical areas and the amygdala have been found to respond with enhanced activation to direct gaze (vs. other gaze direction) stimuli in several different kinds of task contexts, although discrepant results have also been found in some experiments (Itier & Batty, 2009; Senju & Johnson, 2009a). For example, early event-related potentials (ERP) in electroencephalographic (EEG; Conty, Diaye, Tijus, & George, 2007; Pönkänen, Alhoniemi, Leppänen & Hietanen, 2011) and magnetoencephalographic (MEG; Watanabe, Kakigi, Miki, & Puce, 2006) studies have found to be greater for direct gaze than averted gaze, reflecting enhanced early visual processing for direct gaze. Some studies have also found pronounced responses to direct gaze in later ERP components that presumably reflect later stages of social processing (Conty et al. 2007; Itier, Alain, Kovacevic, & McIntosh, 2007; Senju, Tojo, Yaguchi, & Hasegawa, 2005). The amygdala has been suggested to have a central role in directing attention to the eye area (Dal Monte, Costa, Noble, Murray, & Averbeck, 2015) and evaluating the salience and emotional implication of the perceived gaze direction (Itier & Batty, 2009; Senju & Johnson, 2009a). The enhanced activation of the amygdala for direct gaze has been found in several studies (Burra et al., 2013; George, Driver, & Dolan, 2001; Kawashima et al., 1999), although other studies have not confirmed the finding (Hooker et al., 2003; Pageler et al., 2003; Wicker, Perret, Baron-Cohen, & Decety, 2003). Senju and Johnson (2009a) have proposed in their fast-track modulator model that the subcortical face-detection pathway, which includes the amygdala, pulvinar, and superior colliculus, respond strongly to direct gaze and modulates the activation in the cortical social brain network.
1.2 Effects of eye contact on attention and arousal

When a stimulus appears in one’s field of view, attention must be first captured by the stimulus before further information processing. Attention capturing is then followed by sustained attention (or attention engagement) during stimulus-related information processing, and finally, attention is disengaged from the stimulus (Courage, Reynolds, & Richards, 2006). Direct gaze seems to have a special capacity to capture attention, which has been shown in several studies using the visual search paradigm (Böckler, van der Wel, & Welsh, 2014; Conty, Tijus, Hugueville, Coelho, & George, 2006; Doi, Ueda, & Shinohara, 2009; Palanica, & Itier, 2011; Senju, Hasegawa, & Tojo, 2005; Von Grünau, & Anston, 1995; for a critical view, see Cooper, Law, & Langton, 2013). In these experiments, where participants are asked to locate a specific target among distractors, a direct gaze target is generally found faster and more accurately than targets picturing other gaze directions. Direct gaze also seems to hold attention more efficiently than other gaze directions, as disengaging from a face with direct gaze has been found to be slower than from faces with averted gaze (Senju & Hasegawa, 2005), and faces with direct gaze are looked at longer than faces with averted gaze (Mojzisch et al., 2006; Palanica & Itier, 2012; Wieser, Pauli, Alpers, & Mühlberger, 2009).

The abovementioned attentional processes are accompanied by physiological responses of the autonomic and central nervous systems. The orientation response or ‘what-is-it?’-reflex, as first mentioned by Pavlov (1927), refers to bodily changes that initiate the preliminary processing of stimulus information and correspond to the beginning of attentional engagement (Courage et al., 2006). These bodily changes, which occur reflexively and non-voluntarily, include, for example, increase in skin conductance and rapid deceleration of heart rate at the autonomic level, blockage of electroencephalographic alpha-rhythm at the cortical level, and arresting ongoing behaviour and looking towards the stimulus at the behavioural level (Öhman, Hamm, & Hugdahl, 2000).

Skin conductance and heart rate have often been used as indexes of attention and tonic (i.e. long-term fluctuations in arousal level) and phasic (i.e. short-term responses to stimuli) arousal. The focus here will be on phasic responses. Changes in skin conductance are caused by changes in sweat gland activity, which are controlled by the sympathetic branch of the autonomic nervous system. Skin conductance responses (SCR) are often used as an index of affective arousal (Dawson, Schell, & Filion, 2000), and these responses have been associated with the functions of the amygdala (e.g. Laine, Spitler, Mosher, & Gothard, 2009;
Heart rate, on the other hand, is controlled both by the sympathetic and parasympathetic branches of the autonomic nervous system; therefore, an increase in heart rate is caused by increased sympathetic or/and decreased parasympathetic activity, whereas a decrease in heart rate is caused by decreased sympathetic or/and increased parasympathetic activity (Öhman et al., 2000). In the orientation response, a rapid deceleration, presumably caused by parasympathetic activity, occurs during the first few seconds after stimulus onset (when attention is captured), after which the heart rate stays decelerated during sustained attention and the processing of information (Courage et al., 2006; Graham & Clifton, 1966; Öhman et al., 2000). Thus, the deceleration of the heart rate is thought to be closely related to attention and information intake, preparing individuals to respond to the stimulus appropriately. When the processing of information is terminated, the heart rate returns to baseline and might continue accelerating as a sign of a defensive response (Öhman et al., 2000). When assessed during longer time intervals, faster average heart rate is a common index of elevated arousal. Although occurring consistently in response to all novel stimuli, skin conductance responses (SCR) and heart rate deceleration responses are both also known to be sensitive to stimulus significance, such that responses to significant (vs. non-significant) stimuli are enhanced and habituate slower (Bradley, 2009; Öhman et al., 2000). In the present thesis, SCRs will be used as an index of arousal, and HR deceleration response as an index of attention. However, it is good to keep in mind that these two responses are closely intertwined and typically occur simultaneously during the orienting response.

A group of studies from the 70s showed that seeing another person’s direct gaze vs. averted gaze results in heightened levels of arousal, indexed by greater SCRs (Nichols & Champness, 1971) as well as by an increase in average heart rate (Kleinke & Pohlen, 1971) and suppression of EEG alpha activity (Gale, Lucas, Nissim, & Harpham, 1972; Gale, Spratt, Chapman, & Smallbone, 1975). However, several later studies did not find significant differences in arousal in response to direct vs. averted gaze in typical populations (SCR: Donovan & Leavitt, 1980; Joseph, Ehrman, McNally, & Keehn, 2008; Kylliäinen & Hietanen, 2006; Leavitt & Donovan, 1979; Louwerse et al., 2013; Stagg, Davies, & Heaton, 2013; Wieser et al., 2009; EEG alpha arousal: Martin & Gardner, 1979; Pupil dilation: Kampe, Frith, & Frith, 2003). All these latter studies used pictorial stimuli whereas the former studies investigated gaze direction effects in live interaction situations. The differences in stimulus material (live vs. picture) presumably accounted for the discrepancies, as shown by two more recent studies by Hietanen and his colleagues...
(Hietanen et al., 2008; Pönkänen, Peltola, & Hietanen, 2011). In these studies participants were shown images of faces on a computer screen and the same faces live through an electrical shutter. The results showed no effect of gaze direction on SCRs in the picture presentation condition, whereas in the live condition the autonomic responses were significantly larger for direct gaze than averted gaze. Live faces with direct vs. averted gaze were also shown to trigger a pronounced heart rate orientation response (Akechi et al., 2013; Myllyneva & Hietanen, 2015), whereas other studies using pictorial stimulus material did not find differential HR deceleration for direct vs. other gaze direction (Donovan & Leavitt, 1980; Louwerse et al., 2013; Wieser et al., 2009).

Recently, Myllyneva and Hietanen (2015) went further in exploring the preconditions for differential responses to direct vs. averted gaze stimuli and showed that the belief of being seen by another person is a key factor. When participants were led to believe that a live person who they were looking at could not see them because of a half-silvered mirror in between them, direct gaze did not cause enhanced autonomic responses. Thus, although the autonomic responses to direct gaze are presumably triggered by subcortical structures, these responses are modulated by cortical areas in response to task requirements and social context (Senju and Johnson, 2009a), and might be suppressed as a consequence of mentalizing (e.g. when noticing that ‘those eyes don’t see me’).

1.3 Effects of eye contact on cognitive performance

Gaze direction has been shown to have an influence on face-related information processing. In one study, gender discrimination was faster when the pictured person’s gaze was direct rather than averted (Macrae, Hood, Milne, Rowe, & Mason, 2002; however, for contradictory results, see Vuilleumier, George, Lister, Armony, & Driver, 2005). In other studies, faces presented with direct gaze were remembered better than faces presented with averted gaze (Conty & Grèzes, 2012; Hood, Macrae, Cole-Davies, & Dias, 2003; Mason, Hood, & Macrae, 2004). In addition, perceived direct gaze seems to influence cognitive processing even more generally and not solely information processing related to faces. Direct gaze has been shown to have effects on short-term memory performance in remembering word/number sequences, either by enhancing (Falck-Ytter, Carlström, & Johansson, 2015; Fry & Smith, 1975; Kelley & Gorham, 1988) or by impairing performance (Goldfarb, Plante, Brentar, & DiGregorio, 1995; Nemeth, Turcsik,
Effects of direct gaze on verbal episodic memory performance have also been found (Otteson & Otteson, 1980; Sherwood, 1987). In Sherwood’s (1987) study, the direct gaze of a lecturer had a positive effect on learning the content of an oral presentation both in a dyadic and a classroom situation in adults, although not when videotaped presentations were used. Fullwood and Doherty-Sneddon (2006) studied the effects of direct gaze on remembering details of product information presented through videoconferencing equipment. They found that adult participants remembered more details when a person at the video looked at the camera compared with not looking at the camera.

The impact of eye contact on attention and arousal has been suggested to account for these effects of direct gaze on memory performance (Kelley & Gorham 1988; Senju & Johnson, 2009a). It has been suggested that direct gaze helps maintain attention on the task (e.g. Otteson & Otteson, 1980; Sherwood, 1987) or alternatively, direct gaze might be a source of distraction, competing with the limited cognitive resources together with the task at hand (Goldfarb et al., 1995; Nemeth et al., 2013). The latter explanation has been also used to explain the phenomenon of people tending to avert their gaze from instructors’ faces while processing cognitively demanding tasks (Doherty-Sneddon, Bonner, & Bruce, 2001; Doherty-Sneddon, Bruce, Bonner, Longbotham, & Doyle, 2002; Doherty-Sneddon & Phelps, 2005; Doherty-Sneddon, Riba, Calderwood, & Ainsworth, 2009; Doherty-Sneddon, Riba, Whittle, 2012; Glenberg, Schroeder, & Robertson, 1998; Markson & Paterson, 2009; Riba, Doherty-Sneddon & Whittle, 2012). In addition, socio-cultural norms may guide the interpretations of the message carried by direct gaze, and these interpretations might account for the effect of gaze. For example, direct gaze can be interpreted as a sign of approval or disapproval, thereby affecting motivation (Otteson & Otteson, 1980). Finally, it has been suggested that arousal induced by eye contact might mediate the effect of direct gaze on performance, perhaps partly by influencing the above-mentioned social and cognitive processes, especially attention (Falck-Ytter et al., 2015; Kelley & Gorham, 1988). Accordingly, arousal has been regarded as a potential contributor to the so-called social facilitation effect, that is, the effect of another’s presence on performance (Bond & Titus, 1983; Aiello & Douthitt, 2001; Zajonc, 1965).

According to the classic Yerkes-Dodson law (see e.g. Eysenek, 1982), arousal and performance are associated with an inverted U-shape relationship: Increased levels of arousal improve performance up to a certain point after which performance starts to deteriorate with increasing levels of arousal. Further, it has been shown that the relationship between arousal and performance is more
complicated than this, and affected, for example, by the way arousal is defined and quantified (Boucsein, 2012; Eysenck, 1982). Anwy, there is a considerable amount of evidence that cognitive performance is affected by inducing arousal pharmacologically (Addicott & Laurienti, 2009; Giles, Mahoney, Brunyé, Taylor, & Kanarek, 2017), by physical exercise (Lambourne & Tomporowski, 2010), or by manipulation of emotional states (Brunyé, Mahoney, Augustyn, & Taylor, 2009; Gilet & Jallais, 2012). Thus, if eye contact elevates arousal, the arousal could indeed mediate the effect of eye contact on performance.

1.4 Atypical eye contact behaviour in children with autism spectrum disorder

Autism spectrum disorder is a neurodevelopmental disorder containing deficits in social interaction and communication, and includes stereotyped and repetitive behaviour (DSM-V, American Psychiatric Association, 2013). The abnormal use of eye contact is a pervasive characteristic of ASD and is also acknowledged in the diagnostic criteria. Observations with children and adults have shown that individuals with ASD do not look at other people’s eyes as much as typically developing (TD) individuals (e.g. Osterling & Dawson, 1994; Osterling, Dawson, & Munson, 2002; Wang, Shimono, & Shimono, 2015). Eye tracking studies investigating gaze behaviour when looking at social scenes or pictures of faces have similarly shown reduced looking at the eye region (e.g. Klin et al., 2002; Pelphrey et al., 2002; Riby & Hancock, 2009), although the results have not been consistent (see reviews by Bird, Press, & Richardson, 2011, and Falck-Ytter & von Hofsten, 2011). The abnormalities in eye contact behaviour affect the social competence of individuals with ASD. Because of their diminished looking at others’ eyes, individuals with ASD may miss socially relevant cues in communication, such as signals for joint attention (e.g. Böckler, Timmermans, Sebanz, Vogeley, & Schilbach, 2014; Bruinsma, Koegel, & Koegel, 2004; Moore & Dunham, 2014), cues for turn-taking in conversations (cf. Kleinke, 1986), and information about emotional and mental state of the counterpart (e.g. Baron-Cohen, 1997). Further, the reduced use of eye contact affects other people’s impressions, and therefore, further harms social interactions of individuals with ASD.

Although ASD is most often not diagnosed until the age of 3 years (Crane, Chester, Goddard, Henry, & Hill, 2015), the abnormalities in eye gaze behaviour are found to be clearly present earlier according to retrospective analyses of home
videos (Maestro et al., 2005; Maestro et al., 2002; Osterling & Dawson, 1994; Osterling et al., 2002) and studies with high-risk siblings of ASD children (Jones et al., 2014; Jones & Klin, 2013; Ozonoff et al., 2010; Zwaigenbaum et al., 2005). These studies have shown that, although intact at birth (Jones & Klin, 2013), social attention to faces already starts to decline during the first 6 months (Jones & Klin, 2013; Maestro et al., 2005; Maestro et al., 2002), or at the latest, before the child’s first birthday (Osterling & Dawson, 1994; Osterling et al., 2002; Ozonoff et al., 2010; Zwaigenbaum et al., 2005) in children who will develop ASD. A lack of differential neural responses to gaze shifts towards and away from the observer has been found in 6-10 month-aged-infants who were later diagnosed with ASD (Elsabbagh et al., 2012).

There has been debate regarding whether the reduced use of eye contact in ASD is because of the active avoidance of eye contact or because individuals with ASD passively omit social signals related to direct gaze. According to the avoidance hypothesis, individuals with ASD might experience heightened psychophysiological arousal as a response to eye contact which, in turn, might make them feel uncomfortable and lead to the active avoidance of eye contact (e.g. Bowman, Hinkley, Barnes, & Lindsay, 2004; Dalton et al., 2005; Hutt & Ounsted, 1966; Kylläinen & Hietanen, 2006; Skuse, 2003; Tanaka & Sung, 2016). This might be connected to improperly attenuated sympathetic reactions in general (Bal et al., 2010; Hirstein, Iversen, & Ramachandran, 2001). Although some studies with high-functioning, school-aged children with ASD have found experimental evidence for this hyperarousal model by showing that pictorial direct gaze stimuli cause pronounced skin conductance responses in children with ASD (Kylläinen & Hietanen, 2006; Kylläinen et al., 2012; Stagg et al., 2013), other studies have not confirmed these findings (Joseph et al., 2008; Kaartinen et al., 2012; Louwerse et al., 2013). Recently, Nuske, Vivanti, and Dissanayake (2015) measured pupil dilation responses as a measure of emotional arousal to facial pictures with direct vs. averted gaze with younger, 2-5-year-old children with ASD and their age-matched typically developing controls, and found no differences between the groups. Thus, the heightened arousal responses to direct gaze might emerge later in life, or they may be restricted to some subgroups of ASD because of, for example, comorbid social anxiety (Senju & Johnson, 2009b). Furthermore, there is no evidence that the heightened arousal to direct gaze in school-age children with ASD is associated with avoidance-related brain activity, which would support the avoidance hypothesis (Kylläinen et al., 2012). Thus, there is no firm evidence that the primary reason for the reduced use of eye contact in ASD individuals is the
active avoidance of eye contact due to negatively valenced over-arousal (see also a review by Senju & Johnson, 2009b, in support for this conclusion).

The passive omission of direct gaze hypothesis postulates that direct gaze does not capture attention (Senju, Hasegawa, et al., 2005; Senju & Johnson, 2009b) and is not socially motivating (Chevallier, Kohls, Troiani, Brodkin, & Schultz, 2012; Dawson, Webb, & McPartland, 2005; Mundy, 1995; Senju & Johnson, 2009b) for individuals with ASD similarly as it does for typically developing individuals. Several possible neurocognitive mechanisms, whose atypical development might lead to the passive omission of direct gaze, have been suggested (see a review by Senju & Johnson, 2009b). The hypoarousal model proposes that, in early infancy, the amygdala is hypoveractive in response to faces and eye contact, which leads to failure in attaching positive reward value (Dawson et al., 2005) or emotional saliency (Grelotti, Gauthier, & Schultz, 2002) to these stimuli. Thus, this would also lead to reduced arousal responses, for example, to emotional facial stimuli, which has been shown in some studies (Hubert, Wicker, Monfardini, & Deruelle, 2009; Riby, Whittle, & Doherty-Sneddon, 2012). Alternatively, according to a theory by Baron-Cohen (1997), individuals with ASD might fail to infer the social significance of the eyes, because their ‘innate eye direction detecting module’ or theory of mind mechanism might not be functioning properly. Finally, Senju and Johnson (2009b) have proposed in their fast-track modulator model that the abnormalities in eye contact behaviour in ASD might arise from abnormalities in subcortical structures and circuits between subcortical and cortical structures.

Thus, the passive omission hypothesis posits that direct gaze (compared to other gaze directions) does not contain a special potency in capturing and holding attention in individuals with ASD, as it seems to do so for typically developing individuals (Böckler, van der Wel et al., 2014; Conty et al., 2006; Doi et al., 2009; Senju, Hasegawa et al., 2005; Palanica & Itier, 2012; Von Grünau & Anston, 1995). Indeed, the studies by Senju and his colleagues (Senju, Hasegawa, et al., 2005; Senju, Yaguchi, Tojo, & Hasegawa, 2003) have shown that individuals with ASD do not show an advantage in detecting direct gaze faster than other gaze directions in visual search tasks presenting stimulus faces with averted head orientations. However, when only the eyes without the facial context or faces with direct head orientation are presented as stimuli, high-functioning children with ASD do show the detection advantage for direct gaze, presumably because in these setups the detection can rely on low-level graphical features of the eyes instead of configural processing of the whole face (Senju, Kikuchi, Hasegawa, Tojo, & Osanai, 2008). In accordance with these behavioural results, one study showed pronounced
attention-related ERP responses to direct gaze in typically developing children, but not in school-aged children with ASD (Senju, Tojo et al., 2005). Instead, another study showed pronounced MEG responses (Kylläinen, Braeutigam, Hietanen, Swithenby, & Bailey, 2006) to direct gaze in children with ASD and not in typically developing children. Thus, some behavioural and neural evidence supporting the passive omission hypothesis exists, but the evidence is somewhat contradictory and the studies have been restricted to high-functioning school-aged children with ASD, leaving open the question of how the processing of direct gaze has developed in early childhood.
2 THE PRESENT STUDIES

All the three studies presented in this dissertation used measurements of autonomic nervous system activity to broaden the understanding of the effects of eye contact on arousal and attention. In Study I, we investigated whether eye contact with a live person enhances autonomic arousal as compared to seeing a person with averted gaze or closed eyes, and whether these responses are affected by the length of the stimuli or personality characteristics of perceivers. In Study II, the possible consequences of arousal responses on memory performance were examined, that is, whether autonomic arousal mediates the effect of direct gaze on performance in a story recall task. In addition, we investigated whether the belief of being seen by the storyteller moderates the effect of direct gaze on arousal and performance. As it seems that using live persons (instead of pictures) as stimuli leads more consistently to differential effects for direct vs. other gaze direction (Hietanen et al., 2008; Pönkänen, Peltola et al., 2011), a live person was used as the stimulus in Studies I and II. Study III focused on a population with atypical eye contact behaviour, that is, to young children with ASD. The aim of Study III was to investigate whether direct gaze has a specific capacity to capture and hold the attention of young children with ASD in a similar manner as in non-autistic children.

2.1 Arousal responses to eye contact in adults

As described in the introductory chapter, several studies have suggested that eye contact with another person affects autonomic arousal (Gale et al., 1972; Gale et al., 1975; Kleinke & Pohlen, 1971; Nichols & Champness, 1971). However, results showing no differential effects of direct vs. other gaze directions on arousal have also been reported (Donovan & Leavitt, 1980; Joseph et al., 2008; Kampe et al., 2003; Kylläinen & Hietanen, 2006; Leavitt & Donovan, 1979; Louwerse et al., 2013; Martin & Gardner, 1979; Wieser et al., 2009). Although it has already been shown, for example, that the stimulus presentation mode (live vs. picture) has an effect on the results (Hietanen et al., 2008; Pönkänen, Peltola et al., 2011), there is a
need to further investigate in which conditions direct gaze affects a perceiver’s autonomic arousal. The aim of Study I was to investigate whether the duration of seeing direct gaze or individual differences in personality moderate the effects of eye contact on arousal. In addition to the measurement of autonomic arousal, participants’ evaluations of their approach-avoidance tendency in response to different gaze conditions were measured.

2.1.1 Arousal responses to eye contact with variable stimulus duration

It has been suggested that enhanced arousal responses might be restricted only to prolonged direct gaze (Donovan & Leavitt, 1980; Senju & Johnson, 2009a). This suggestion has been based on the notion that, in the above-mentioned studies, the stimulus duration has been rather long (5–20 s) which might be considered as breaking social norms. In everyday encounters, the average length of a single mutual gaze is only about 1.5–3 seconds (Argyle, 1981; Mobbs, 1968). In a recent study, where participants’ preferred direct gaze duration was evaluated by using videoclips, the average preferred gaze duration was only a little longer than 3 seconds (Binetti, Harrison, Coutrot, Johnston, & Mareschal, 2016). However, the question of whether enhanced arousal is restricted only to prolonged eye contact has not been experimentally tested.

To investigate whether the length of presentation of gaze stimuli moderates the effects of direct gaze on arousal, facial stimuli were presented with variable stimulus durations in Study I. Live faces with different gaze directions were presented with short (2s) and long (5s) durations through a computer-controlled electronic shutter (part 1), or the participants were asked to choose the stimulus duration themselves by allowing them to open and close the shutter (part 2). By allowing the participants to control the stimulus duration themselves, we aimed to measure their preferred eye contact duration and investigate whether the preferred duration is correlated with arousal.

Based on previous research, we predicted that seeing direct gaze would result in larger SCRs than seeing faces with other gaze directions. Moreover, we hypothesized that longer presentation times of the direct gaze stimuli would result in larger SCRs than shorter ones. We predicted that the participants would choose to look at the direct gaze for a shorter time than the averted gaze in the self-controlled situation; a previous study using similar live face stimuli showed that a live face with direct gaze was evaluated to evoke less positive feelings than averted
gaze (Hietanen et al., 2008). Further, as it has been speculated that the reason for terminating eye contact might be to reduce arousal evoked by it (Argyle, 1981; Ellsworth, Carlsmit, & Henson, 1972; Ellsworth and Langer, 1976; Field, 1981), we expected that higher arousal responses would be connected to longer looking times in the direct gaze condition.

2.1.2 Individual differences

In addition to the length of eye contact, individual differences might affect responses to eye contact. Several studies have investigated the effects of personality characteristics on people’s eye contact behaviour (e.g. Berry & Hansen, 2000; Kendon & Cook, 1969; Larsen & Shackelford, 1996; Mobbs, 1968; Wiens, Harper, & Matarazzo, 1980) and the impressions people form of others’ personality based on their gaze behaviour (Argyle, 1981; Brooks, Church, & Fraser, 1986; Cook & Smith, 1975; Knackstedt & Kleinke, 1991; Larsen & Shackelford, 1996). It has been shown, for example, that extroverts as compared to introverts look more frequently at other people, the percentage of direct gaze is greater, and single glances are longer (Kendon & Cook, 1969; Mobbs, 1968; Wiens et al., 1980). Recently, two dimensions of Big Five personality theory, extraversion and agreeableness, were related to increased attention to the eyes, whereas openness to experience was related to decreased attention to the eyes of people in social video scenes (Wu, Bischof, Anderson, Jakobsen, & Kingstone, 2014). In another study, both agreeableness and openness to experience were associated with increased attention to the counterpartner’s face in an initial interaction situation (Berry & Hansen, 2000). Neuroticism has been associated both with behavioural direct gaze avoidance (pronounced tendency to look at a person with direct gaze for shorter periods of time than a person with averted gaze) and avoidance-related frontal brain asymmetry responses to direct gaze (Uusberg, Allik, & Hietanen, 2015). Moreover, social anxiety, which is common in individuals with high neuroticism (Cox, Hewitt & McLeod, 1997), has been associated with elevated arousal responses to direct gaze (Myllyneva, Ranta, & Hietanen, 2015; Wieser et al., 2009). Indications of individual differences in motivational brain responses to direct vs. averted gaze directions were also found in the study by Pönkänen and Hietanen (2012).

Thus, personality characteristics seem to affect eye contact behaviour as well as neural responses to direct gaze. There have been speculations that arousal
responses might explain some differences in gaze behaviour: It has been suggested that extroverts might be less aroused by direct gaze, because of which they could tolerate it for longer than introverts before terminating eye contact (Argyle, 1981). In Study I, we investigated whether perceivers’ personality characteristics modulate arousal responses and behavioural responses to different gaze directions. As a behavioural response, participants were asked to evaluate their subjective tendencies to either approach or avoid a person. We expected that extraversion and emotional stability (inverse to neuroticism) would be negatively associated with arousal responses to direct gaze, and people with high extraversion and emotional stability would be more willing to approach a person with direct gaze than those who score low on these personality dimensions. Agreeableness and openness to experiences might also be positively associated to the self-evaluated approach tendency in response to direct gaze.

2.2 The mediating effect of arousal between eye contact and memory performance

In previous studies investigating the effect of another person’s direct gaze on performance, it has often been speculated that the effects might be explained by the effect of eye contact on arousal (e.g. Falck-Ytter et al., 2015; Kelley & Gorham, 1988). However, there is no direct evidence for this suggestion. Thus, in Study II, we wanted to specifically investigate whether arousal has a mediating role between eye contact and memory performance. In this study, participants were asked to memorize short stories that were read for them by a storyteller who was either looking directly at the participant or looking downwards. The participants’ skin conductance was measured during the storytelling to have a measure of sympathetic arousal. We predicted that gaze direction would have an effect on memory performance, but as both positive and negative effects of direct gaze have been reported, we did not hypothesize about the direction of the effect. Importantly, however, we hypothesized that the effect of direct gaze would be mediated by autonomic arousal. Because several studies have found gender differences in gazing patterns in social interaction (e.g. Argyle & Dean, 1965; Kendon & Cook, 1969; Mulac, Studley, Wiemann, & Bradac, 1987; Whitelock & Scanlon, 1998) as well as some gender differences in pupil dilation responses to direct gaze (Porter, Hood, Troscianko, & Macrae, 2006), both same-sex and mixed-
sex male and female pairs were included to control for the possible effects of gender.

2.2.1 Belief of being seen

As described above, previous research has implied that differential responses to direct vs. other gaze directions are found only when participants know that the other person is seeing them, and not when using pictures as stimuli (Hietanen et al., 2008; Pönkänen, Peltola et al., 2011), or when they believe that a live model’s view is blocked (Myllyneva & Hietanen, 2015). In addition, there are some indications that direct gaze might affect memory performance differently when participants know that they are or are not seen by an instructor. In a study by Sherwood (1987), recall was not significantly enhanced by direct gaze when the presentation was shown through a video, although the effect was observed in a corresponding experiment that used a live presentation. Instead, in a study by Fullwood and Doherty-Sneddon (2006), differential effects of direct vs. averted gaze on recall were found when participants were presented product information through a video, but were told that they were seen by the person giving the information through a video-link. The discrepancy between these two studies might be explained by the participants’ belief of being seen by the instructor.

Thus, in Study II, we aimed at investigating whether the belief of being seen by another person has an impact on the effect of gaze on memory performance. Participants’ belief of being seen or not being seen by the storyteller was manipulated with a deception procedure similar to that of Myllyneva and Hietanen (2015). Our hypothesis was that the effect of direct gaze on memory performance would be stronger when the participants believed that they were seen by the storyteller, compared with not being seen, or that the effect of gaze direction might be absent in the latter condition. The lack of differential arousal responses to direct vs. downcast gaze might explain the lack of effects on performance when participants believe that they are not being seen.
2.3 Orienting to direct gaze in young children with and without ASD

As described in the introduction, there is some evidence from visual search studies with school-aged children and adults with ASD that direct gaze does not capture the attention of ASD individuals as efficiently as it does in typically developing individuals (Senju, Hasegawa, et al., 2005; Senju et al., 2003), thereby supporting the passive omission hypothesis. However, some critics of visual search tasks have suggested that visual search paradigms are vulnerable to methodological problems related to the perceptual properties of stimulus arrays, and have questioned whether a conclusion about the prioritized attention capture of direct gaze can be made using that paradigm (Cooper et al., 2013). To further examine whether passive omission might be a reason for reduced eye contact behaviour in ASD, in Study III, we will broaden the perspective from the explicitly instructed visual detection of direct gaze to physiological orienting that is known to be affected by the emotional and social salience of stimuli (Bradley, 2009; Öhman et al., 2000).

Another gap in the current literature relates to the fact that the most of the earlier research has focused on high-functioning school-aged children with autism, mostly because of challenges in guiding young, nonverbal, and low-functioning children through the experimental procedures (cf. Kylliäinen, Jones, Gomot, Warreyn, & Falek-Ytter, 2014). However, investigating young, low-functioning children is needed to better understand the developmental origins of atypical eye contact behaviour in ASD. Compared to high-functioning children, young and low-functioning children have had, for example, fewer opportunities to learn compensatory strategies for their disabilities. In addition, research focusing on different subgroups of ASD is needed, because all the subgroups within the spectrum might not respond to direct gaze similarly (see Hirstein et al., 2001; Joseph et al., 2008; Kaartinen et al. 2012; Kaartinen, Puura, Himanen, Nevalainen, & Hietanen, 2016, Riby & Hancock, 2009). In Study III, we were interested in investigating whether direct gaze has a specific capacity to capture and hold the attention of young, low-functioning children with ASD similar to the way it does for non-autistic children.

Previous studies have resulted differences in skin conductance responses to direct vs. other gaze direction between ASD and TD children when using dynamic pictorial stimuli (Kylliäinen & Hietanen, 2006; Kylliäinen et al., 2012). Thus, although pictorial stimuli might not reveal differences between direct and averted gaze as robustly as live stimuli, differential findings between ASD and TD
populations have been found while using pictorial stimuli. Dynamic stimuli, compared to static stimuli, have been found to better reveal the abnormalities in gaze behaviour in children with ASD (Saitovitch et al., 2013). Hence, also considering the advantages of using pictorial stimuli (better control of stimuli, opportunities to use several identities with one participant, and practical reasons), dynamic pictorial stimuli were used in Study III. The stimuli depicted illusionary gaze shifts where a face with downcast gaze appeared to raise the gaze either towards the participant or laterally away from the participant. The stimulus heads were laterally rotated to ensure that the low-level visual properties of the eyes would not affect the results (cf. Senju et al., 2008). Because individuals with ASD have been found to have diminished fixation to the eyes in some previous studies (e.g. Klin et al., 2002; Pelphrey et al., 2002), the gaze behaviour of the children was measured with an eye tracker to control the possibility that the differences in psychophysiological responses would be caused by differences in gazing patterns. However, because we were interested in investigating the physiological aspects of orienting caused by the social salience of direct gaze and not the perceptual detection of gaze shifts, the participants’ attention was purposefully directed to the eye region by the task properties. Thus, we expected to not find differences in gaze behaviour between the groups.

To summarize, Study III aimed at investigating whether young, low-functioning children with ASD show orienting responses that are similar to their chronological age- and developmental age-matched peers as measured with heart rate deceleration to dynamic shifts of eye gaze to direct vs. averted direction. The group of developmental age-matched children was included to investigate whether developmental delay could affect physiological responses to gaze shifts. It was predicted that the typically developing (TD) children and children with developmental delay (DD) would show an enhanced heart rate orienting response to direct gaze compared to averted gaze. On the other hand, we expected to not find differences in orienting response to direct vs. averted gaze in children with ASD.
3 METHODS AND RESULTS

3.1 Study I

3.1.1 Methods of Study I

A group of 33 adults (18 women, age $M = 22.8$ years, range = 19–43 years) volunteered to participate in Study I. Due to some technical problems and artefacts in the data, the final analysis was based on the data from 30 participants (17 women) in part 1 (fixed stimulus duration) of the experiment, and on the data from 28 participants (17 women) in part 2 (self-controlled stimulus duration). The questionnaire that was used to measure personality characteristics was obtained from all except one participant.

The experiment was conducted using a liquid crystal shutter window that was attached to a frame on the table between the model person and the participant. The shutter window was switched between opaque and transparent states for predetermined lengths by a computer (part 1) or by hand with a switch box attached to the shutter (part 2). This shutter window enabled the presentation of live faces as stimuli in a very controllable fashion with variable durations. Two female experimenters served as stimulus faces; the identity of the face was approximately counterbalanced across the male and female participants. During the experimental trials, the experimenter had a neutral expression, but the gaze direction varied in a pseudo-randomized order. In part 1, the participant saw two blocks of 18 trials (6 trials in each condition) where the model’s gaze was either direct, averted (30°, left or right), or the eyes were closed. In part 2, only direct and averted gaze stimuli were presented with 4 trials in both conditions in a pseudo-randomized order.

In the first part of the experiment, two stimulus durations were used. In one block, the presentation time was 2000 ms and 5000 ms in the other. The order of the blocks was counterbalanced across the participants. During the inter-stimulus interval (varying from 21 to 25 s), the shutter remained opaque. A short and soft audio signal was presented through speakers 5 s before the start of the next trial to
direct the participant’s attention to the shutter. The participant was instructed to look at the stimuli, and after the shutter was closed, to make a subjective evaluation about his/her tendency to approach (‘evaluate whether you would like to approach or make contact with the person, for example, by saying something’) or avoid (not to make contact with) the model. The evaluations were made on a continuous scale between these two options with a slide potentiometer fixed into a small box that was positioned on the participants’ lap.

In the second part of the experiment, the participants were asked to choose how long he/she wanted to look at the face, with the following instructions: ‘The time that different people feel it natural to look at another person’s face in different situations varies. Now, we want to measure the time you feel it is natural to look at the face in the present situation. There are no right or wrong answers. This is not a contest of who can stare the longest at the other person; the looking-time can also be quite short’. In each trial, the model told the participant when he/she was allowed to open the shutter, ensuring that the inter-stimulus interval was about 20s. After having the permission, the participant could open and close the shutter with a switch box that he/she was holding on his/her lap. The duration of how long the participant kept the shutter open in each trial was measured and averaged in the direct gaze and averted gaze conditions.

During the stimulus presentation, the participants’ skin conductance reactions (SCR) were measured with two electrodes (Ag/AgCl) attached to their index and middle fingers. The maximum amplitude change was measured during a 4-s time period starting after 1 s from stimulus onset, in relation to the baseline level at stimulus onset. The data were averaged in each condition for each participant, including those trials with a zero response, and thus, forming a measure called the magnitude of the SCR, which combines the response size and frequency (Dawson et al., 2000).

After the experiment, the participants were asked to complete the PK5 personality questionnaire (Psykologien kustannus; Oy, 2007) at home and return the questionnaire by mail. PK5 is a Finnish personality test based on the Big Five personality factors (extraversion, agreeableness, conscientiousness, emotional stability, and openness to experience). The questionnaire consists of 150 statements that the participant answers on a 5-point Likert-scale (I agree perfectly—I don’t agree at all).
3.1.2 Results of Study I

The results of both parts (1 and 2) of the experiment showed that, as expected, direct gaze resulted in enhanced SCRs when compared to averted or closed eyes (Figure 1). The prefixed stimulus presentation time (2 vs. 5 seconds) did not have an effect on the results. As expected, in the condition where the participants controlled the stimulus duration, they chose to look longer at the averted gaze ($M = 5.5$ s) than direct gaze ($M = 4.0$ s). The magnitude of the SCRs for direct or averted gaze did not correlate with the average looking time in the respective gaze conditions in part 2. Overall, the SCRs were greater in the self-controlled ($M = 0.72 \mu$S) than the fixed ($M = 0.24 \mu$S) timing condition.

The skin conductance responses did not correlate with any personality factors. However, the participants’ evaluations about their approach-avoidance tendency in the direct gaze condition revealed personality differences. About one half of the participants evaluated the direct gaze as approachable ($n = 13$), while the other half evaluated it as avoidable ($n = 16$). These two groups of participants were compared on the five personality dimensions obtained from the PK5 questionnaire. The two groups differed significantly on the emotional stability dimension. Those participants who had evaluated the direct gaze as approachable were more emotionally stable than those who had evaluated direct gaze as avoidable.

![Figure 1](image_url)

**Figure 1.** A: Mean SCRs (and SEMs) in the direct, averted gaze, and closed eyes conditions as a function of presentation time in part 1. B: Mean SCRs in the direct and averted gaze conditions with self-controlled presentation time in part 2.
3.2 Study II

3.2.1 Methods of Study II

Twenty-four men (age \( M = 27.1 \), range = 19–53 years) and 22 women (age \( M = 25.5 \) years, range = 19–39 years) participated in the study. After discarding data (due to technical problems), 20 men and 21 women contributed to the story recall data, and 18 men and 19 women contributed to the skin conductance data. Two young adults, a male and a female, served as storytellers. One half of the participants were assigned to the experiment with a same-sex storyteller, and the other half with an opposite-sex storyteller.

A shutter window similar to the one in Study I was used in the experiment. A storyteller, who was facing the participant behind the shutter window, read four short stories to the participant sequentially. After each story, which lasted for about 1 minute, the participant was asked to repeat everything that she/he could recall from the story. The participant was informed that the experimental situation was filmed by a hidden video camera for the purpose of recording his/her answers. The shutter window was kept transparent only during the storytelling; thus, the participant could see the face of the storyteller only during that phase of the task.

The stories were read in two different gaze conditions: the storyteller either made eye contact with the participant most of the time during storytelling or was looking downwards throughout. In addition, two belief conditions were created: ‘the belief of being seen’ condition where the participant believed that she/he was seen by the storyteller, and ‘the belief of not being seen’ condition where the participant believed that she/he was not seen by the storyteller, even though she/he saw the storyteller. The latter condition was created with a deception procedure where the participant was led to believe that when a special half-silvered mirrored sheet was slid over the window, the storyteller could not see the participant even though the participant could see the storyteller. Thus, the experiment contained four conditions in a 2 x 2 design.

The memory performance of the participant was scored from the videos by an assistant who was blind to the conditions. One point was given for every pre-defined detail that the participant had recalled, the maximum score being 50 points for each story. The scores for each story were standardized across all participants to control for differences in the difficulty of the stories.
To measure the participants’ sympathetic arousal, skin conductance was measured during the storytelling with two electrodes (Ag/AgCl) attached to the index and middle fingers of the participants’ left hand. The variability in skin conductance during the storytelling was analysed by calculating the area bounded by the filtered skin conductance curve and the abscissa. This method (adapted from Figner & Murphy, 2011) combines the frequency and shape parameters (for instance, amplitude and recovery time) of phasic skin conductance responses.

Statistical analysis was first performed with an analysis of variance separately for arousal measures and memory performance with gaze direction (direct, downcast) and state of belief condition (belief of being seen, belief of not being seen) as within-subject variables and the gender of the storyteller and participant as between-subject variables. Next, a path analysis was performed to investigate whether the arousal mediated the association between gaze direction and memory performance. The participants’ and storytellers’ gender were included as moderators in the analysis.

3.2.2 Results of Study II

Among male participants, effects of gaze direction were found both on skin conductance variability and memory performance. Unexpectedly, the storyteller’s gaze direction did not affect female participants’ skin conductance variability or memory performance. Overall, the female participants had lower skin conductance variability than males. No effects of ‘belief manipulation’ were found in either gender group on skin conductance variability or memory performance.

Irrespective of the storyteller’s gender, there was more variability in male participants’ skin conductance in the direct gaze condition than the downcast condition, indicating that they were more aroused during the direct gaze condition. The gaze direction had a differential effect on male participants’ memory performance depending on whether the storyteller was male or female. When the female storyteller looked directly into the participant’s eyes while reading the stories, the performance was worse compared to the downcast condition. In contrast, when the storyteller was male, the male participants performed better when the storyteller used direct gaze compared to downcast gaze. The path analysis (see Figure 2) showed that the arousal mediated the effect of direct gaze on performance. The effect of arousal was negative: the more aroused the male participant was, the worse his performance. However, this process was paralleled
by another process that was moderated by the storyteller’s gender. That is, when the storyteller was male, the arousal-mediated process was accompanied by another process that positively affected the performance. As a consequence of this process, the enhanced memory performance was observed when the male storyteller used direct gaze (compared to downcast gaze), despite enhanced arousal.

Figure 2. Conceptual diagram of the path model for the male participants showing regression coefficients, bootstrapped standard errors in brackets, and significances with asterisks. A female storyteller and averted gaze were used as references in the models.
3.3 Study III

3.3.1 Methods of Study III

Twenty young children with ASD, 20 typically developing children (TD), and 18 children with developmental delay (DD) without ASD participated in Study III. The diagnoses of the children with ASD were confirmed with the *Autism Diagnostic Observation Schedule* 2 (ADOS-2, Lord et al., 2012) and with the parental *Autism Diagnostic Interview-Revised* (ADI-R; Rutter, Le Couteur, Lord, & Faggioli, 2005). The lack of marked autistic behaviour in the TD and DD groups was confirmed with the *Social Communication Questionnaire* (SCQ, Rutter, Bailey, & Lord, 2003). A sufficient amount of data for Study III was obtained from 12 ASD (chronological age $M = 3.9$ years, range = 2.6–5.3 years; developmental age $M = 2.5$, range = 1.2–4.2), 17 chronological age-matched TD (chronological age $M = 4.2$, range = 2.4–5.8), and 16 developmental age-matched children with DD (developmental age $M = 2.8$, range = 1.8–3.8).

The children performed a computerized task while their heart rate and eye movements were recorded. One trial of the task is presented in Figure 3. First, an animated button that served as an attention grabber appeared in the middle of the screen. Next, a facial picture showing a head turned 45 degrees to the left or right and keeping eyes down appeared on the screen. After two seconds, the eyes turned upwards, either towards the camera (direct gaze) or towards the direction of the head (averted gaze), while the position of the head remained still. After three seconds, the head turned towards the camera without altering gaze direction. After 1 second, the participant saw a picture of a joystick and heard an instruction: ‘now you’. This instructed the child to either pull or push the joystick according to the given instructions, and the face either loomed towards or away from the child, respectively, lasting for 3 seconds. A maximum of 24 trials were presented for each child, 12 trials in each gaze condition.
As we wanted to specifically measure the orientation response to shifts of eye gaze (separated from the orientation response towards a face as such), measurements of the deceleration responses were time-locked to the shifts in eye gaze. The QRS complexes of the electrocardiogram signal were detected and interbeat intervals (IBI) were calculated by measuring the time intervals between successive R-waves. Based on the IBIs, the estimation of the mean heart rate (beats per minute, bpm) was calculated for each 500 ms period starting from 500 ms before and ending at 2 seconds after the gaze shift. The 500-ms period before the gaze shift was used as a baseline, which was subtracted from the mean heart rate of each following 500 ms to form a measure for heart rate change.

The children’s behaviour in every trial from the videos was analysed offline (from a camera that was attached above the computer screen) and only those trials where the children were looking at the screen were approved for the heart rate analysis. The children’s attention was directed to the eye region by the task design. First, by an attention grabber that was positioned at the level of the eyes, and second, by the movement occurring in the eyes during the time of interest. However, we also investigated whether the children with ASD differed from the control groups in how they looked at the eye region during the time window when the heart rate deceleration was measured. The eye movements were recorded using a corneal-reflection eye-tracking system that was attached to the computer screen.
Twelve children with ASD, 14 children with TD, and 14 children with DD had sufficient valid eye tracker data for the analysis. The area of interest for the eyes (eyes AOI) was defined as a rectangle with 220 x 90 pixels around the eyes (see Figure 4). Two analyses were performed. First, the looking time for the eyes AOI in relation to the looking time for the whole screen was analysed during the 2 seconds after the gaze shift. Second, we wanted to find out whether the participants were looking at the eye region during or shortly after the gaze shift, in order that the deceleration in heart rate could be expected. Thus, the frequency of trials where the latency for the eyes AOI after the gaze shift was smaller than 500 ms was calculated and divided by the total number of accepted trials for each gaze condition.

![Figure 4. The area of interest for the eyes.](image)

### 3.3.2 Results of Study III

The analysis of the heart rate showed that both TD children and children with DD responded to the direct gaze with heart rate deceleration, indicating attention orienting whereas no deceleration was observed for averted gaze (see Figures 5 and 6). The average heart rate deceleration during the two seconds after the gaze shift was significantly greater for direct gaze than averted gaze in both groups. On the other hand, no heart rate deceleration response to direct gaze was observed in children with ASD (Figures 5 and 6). The difference between the average HR deceleration in direct gaze and averted gaze conditions was not statistically significant in the ASD group. The eye movement data analysis showed that, in both gaze conditions, there were no differences between the groups in how long
the participants looked at the eye region during the analysis period (median 61.5% for direct gaze, 61.9% for averted gaze). Moreover, there were no significant differences between the groups in the frequency of trials when the participants’ gaze entered the eyes AOI within the first 500 ms after the gaze shift (median 85.7% for direct gaze, 88.9% for averted gaze). Thus, the lack of heart rate deceleration response in children with ASD was not explained by reduced looking at the eye region.

**Figure 5.** Mean heart rate change (and SEM) after a gaze shift to the direct and averted directions in children with ASD, typically developing children, and children with developmental delay without ASD.

**Figure 6.** Individual means (triangles) of heart rate change, and group means (solid lines) in direct and averted gaze conditions in typically developing children (TD), children with developmental delay (DD), and children with ASD.
4 DISCUSSION

The three studies presented in the thesis investigated the effects of eye contact on perceivers’ autonomic responses related to arousal and attention. The first question was, whether direct gaze, compared with other gaze directions, causes enhanced arousal responses. Specifically, we investigated whether gaze duration or personality characteristics of participants affect the arousal responses triggered by direct gaze. In Studies I and II, it was shown, confirming our hypotheses, that the perceived direct gaze of a live person compared with other gaze directions caused enhanced arousal. This was observed irrespective of stimulus duration in Study I, and thus, showed that enhanced arousal responses are not restricted to prolonged eye contact, as previously speculated (Donovan & Leavitt, 1980; Senju & Johnson, 2009a). Furthermore, no correlations were found between Big Five personality factors and arousal responses. However, some interesting effects of personality on behavioural responses were found. Those participants who evaluated that they would like to approach a person with a direct gaze were emotionally more stable than those who evaluated that they would rather avoid her.

The second question of the thesis was whether autonomic arousal caused by eye contact mediates the effect of eye contact on a perceiver’s memory performance. In accordance with our hypotheses, it was shown, in Study II, that arousal has a mediating role between direct gaze and memory performance. However, the path analysis of the data also demonstrated a complicated nature of the effect of direct gaze on performance. In addition to the arousal-mediated process, another process besides autonomic arousal was also explaining the effect of eye contact on performance, and this process was moderated by the storyteller’s gender. We suppose that this process is related to effort allocation and motivation. Surprisingly, the effects of eye contact on both arousal and performance were observed only among male and not female participants in Study II. In addition, the effect of the belief of being seen by the storyteller on arousal and memory performance were investigated, but no effects were found.

The third question was whether young, low-functioning children with ASD show an atypical orienting response to direct gaze, when compared with typically developing children or children with developmental delay. This question had arisen
from a debate whether children with ASD might omit signals related to direct gaze. It was shown, in Study III, that typically developing children and children with developmental delay without ASD responded with a stronger orientation response to direct gaze than averted gaze, whereas the children with ASD did not show the orienting response to direct gaze.

Below, I will first discuss the effect of eye contact on autonomic arousal in the light of the present studies and current literature. Next, I will consider the present findings of the effects of eye contact on memory performance in detail. Finally, I will discuss how the findings of the lack of the orientation response in children with ASD expands the understanding of eye contact difficulties in ASD.

4.1 Arousal responses to eye contact

Previous research has shown conflicting findings on whether direct gaze causes enhanced arousal responses in perceivers. Consistent with several previous studies (Hietanen et al., 2008; Nichols & Champness, 1971; Pönkänen & Hietanen, 2012; Pönkänen, Peltola et al., 2011), Studies I and II showed that participants responded to direct gaze with enhanced skin conductance responses when compared with averted gaze or closed eyes. As previous studies have used rather long stimulus durations compared with durations of average eye contact in social interaction (cf. Argyle, 1981; Mobbs, 1968), we specifically investigated whether enhanced arousal responses are restricted to the prolonged exposure of direct gaze in Study I. The results showed that this was not the case. A short, 2-second stimulus duration enhanced arousal responses similar to a longer 5-second stimulus duration.

Interestingly, in part 2 of Study I, where participants were allowed to control the stimulus duration themselves, the overall SCRs were greater in comparison to part 1, where the stimulus presentation time was predetermined. As all the subjects performed part 2 after part 1, smaller and not larger responses could have been expected in part 2 due to habituation, which makes this result even more interesting. It might be that participants’ power to control the looking time may have enhanced their role as an active partner in the interaction, although in a very simplified manner, and this might have increased autonomic responsivity. In a recent study by Myllyneva, Ranta et al. (2015), where a similar methodology was used, no such enhancement of SCRs was reported in participant-controlled looking time vs. predetermined looking time conditions. However, differences in responses to direct vs. averted gaze between participants with and without social anxiety were
revealed only when participants controlled the looking time themselves. Thus, in the future, the participant’s level of activity in experimental situations is worthy of consideration when the effects of direct gaze are investigated.

When participants themselves controlled how long they looked at the stimuli, they chose to look less for direct gaze than averted gaze, as predicted. The average looking time for direct gaze, 4 s, was only slightly longer than the previously reported average length of eye contact in social encounters (Argyle, 1981; Mobbs, 1968), or the average preferred direct gaze duration evaluated by participants when looking at videos (Binetti et al., 2016). An interesting possibility is that shorter looking times for direct vs. averted gaze might be related to enhanced arousal for direct gaze. It has been proposed that the purpose of cutting off eye contact might be to reduce the tension it evokes (Argyle, 1981; Ellsworth & Langer, 1976; Field, 1981). Moreover, in a recent study, preferred direct gaze duration when looking at videos of actors’ faces was positively correlated with increases in pupil size during the initial processing of direct gaze stimuli, suggesting that autonomic reactions might be correlated with the preference of direct gaze duration (Binetti et al., 2016). However, in Study I, the length of the stimulus duration did not correlate with the magnitude of skin conductance responses. Thus, the data did not support that the level of arousal influenced the participants’ chosen length to look at the person with direct (or averted) gaze.

Based on the previous literature, we had hypothesized that personality traits, namely extraversion and emotional stability, would be negatively associated with arousal responses to eye contact. However, no significant correlations were found between participants’ Big Five personality traits and skin conductance responses to direct gaze. Consistent with our results, Big Five personality traits were not correlated with pupillary responses to direct gaze stimuli with variable stimulus duration in a study by Binetti et al. (2016) that had a very large sample size (nearly 500 participants). Thus, so far, no effects of personality traits on autonomic responses caused by eye contact have been reported. However, as personality effects within normative variation have not been excessively studied, and as our study was limited by a relatively small sample size, more research is needed to make definite conclusions regarding whether personality moderates the effects of eye contact on arousal.

On the other hand, effects of personality were found in self-evaluated approach-avoidance tendencies in response to direct gaze; those who evaluated that they would like to approach a person with a direct gaze were emotionally more stable (i.e. more calm and self-confident) than those who evaluated that they would
rather tend to avoid a person with a direct gaze. Consistent with this result, Uusberg et al. (2015) found that neuroticism (inverse to emotional stability) was negatively associated with left-sided frontal EEG asymmetry, indicating approach motivation, in response to direct gaze. In their study, participants with higher neuroticism were also likely to look for a shorter time at direct gaze than averted gaze in a participant-controlled looking time task similar to our study. These findings fit together with studies showing that neuroticism (Campbell & Rushton, 1978) and low self-esteem (Vanhromme, Hermans, & Spruyt, 2011) are associated with gaze avoidance. No connections between other personality dimensions and self-evaluated approach-avoidance tendency were found in Study I, although personality differences in extraversion (Mobbs, 1968; Wiens et al., 1980, Kendon & Cook, 1969, Wu et al., 2014), agreeableness, and openness to experience (Berry & Hansen, 2000; Wu et al., 2014) have been found to be associated with gaze behaviour.

4.2 The mediating role of autonomic arousal between eye contact and memory performance

The results of Study II showed that, as predicted, the storyteller’s gaze direction affected participants’ memory performance, although only in male participants, and arousal had a mediating role between gaze direction and performance. The effect of arousal on performance was negative. Interestingly, however, our path analysis showed that parallel to this arousal-mediated process, another process between gaze and performance affected performance positively. This process was moderated by the storyteller’s gender. When the storyteller was male, the positive effect of this process on performance was stronger than the negative effect of arousal. As an outcome, the effect of direct gaze on performance was positive when a male participant was facing a male storyteller. Contrarily, when a male participant was facing a female storyteller, direct gaze had a negative effect on performance because of the arousal-mediated process.

Why was the effect of arousal on performance negative in our experiment? According to the Yerkes-Dodson law (see Eysenck, 1982), at lower states of arousal, increases in arousal improve performance, but when the level of arousal reaches a certain point, further increase deteriorates performance. Furthermore, task difficulty has been found to interact with arousal; the same level of arousal might improve performance in an easy task, while deteriorating performance in a
difficult task (Eysenck, 1982). It may be that our participants’ level of arousal was rather high, for example, due to the experimental situation, and the task was presumably rather challenging. Clearly, however, this is only speculation, as our experimental design did not allow us to evaluate whether the level of our participants’ arousal was high, moderate, or low, when compared to the entire range of arousal levels, nor did we manipulate task difficulty. Altogether, it is possible that, in some other situation (e.g. if a person’s initial level of arousal is very low), the mediating effect of arousal between eye contact and performance might be positive rather than negative. Thus, based on our finding, one cannot draw conclusions about whether it was arousal or some other process that contributed to the positive effect of direct gaze on memory performance in previous studies (Falck-Ytter et al., 2015; Fry & Smith, 1975; Fullwood & Doherty-Sneddon, 2006; Kelley & Gorham, 1988; Sherwood, 1987).

What could be the other process that, according to our path analysis, was positively influencing performance parallel to the arousal-mediated process? Interestingly, the existence of at least two operationally distinct mechanisms underlying the effect of another person’s presence on performance has been suggested, one related to unintentionally induced arousal and the other related to voluntary effort allocation (Kushnir, 1981). Additionally, in multidimensional arousal theories, ‘affective arousal system’ is considered separate from ‘effort system’ (Boucsein, 2012; Eysenck, 1982). With the effort system, an individual can compensate the negative effects of affective arousal when needed (Eysenck, 1982). These systems are regarded to also have different neurophysiological underpinnings, and accordingly, the activation of these systems is presumably reflected differently in different psychophysiological measures (Boucsein, 2012). The phasic changes in skin conductance that we used in our study are a commonly used index of affective, sympathetic arousal (see Boucsein, 2012; Lang & Bradley, 2010). Instead, effort allocation has been investigated with heart rate variability (e.g. Börger et al., 1999; Segerstrom & Nes, 2007), pupil dilation (Steinhauer, Siegle, Condray, & Pless, 2004), or tonic changes in cortical arousal (Howells, Stein, & Russell, 2010). In future studies, it would be interesting to use these measures together with skin conductance to investigate whether the other process explaining the effect of eye contact on performance is related to effort allocation. There is a good reason to believe that this could be the case, because direct gaze can be considered a motivational stimulus that promotes the amount of effort allocated to the task. For example, Conty et al. (2016) proposed that direct gaze automatically triggers self-referential processes that are at least partly independent from the
arousing effects of direct gaze, and these processes have generally positive effects on cognition. The self-referential processes would presumably motivate participants to put more effort in the task performance, leading to positive performance outcomes.

Interestingly, for some reason, the positive effect of the presumed effort allocation process was seen only when male participants were looked at by a male storyteller, and not when looked at by a female storyteller. Our suggestion is that this might be explained by the interpretation of the meaning of a male vs. female direct gaze, which is influenced by socio-cultural norms (Burgoon, Guerrero, & Floyd, 2010; Henley, 1995). For example, men might interpret a woman’s direct gaze as a sexual cue (Abbey & Melby, 1986), and because of that, instead of putting more effort on task performance, they might put effort on self-monitoring in order to make a good impression. Similar explanations were given for results showing that interacting with a woman, and even merely anticipating an interaction with a woman, negatively influenced male participants’ performance in cognitively demanding tasks (Karremans, Verwijmeren, Pronk, & Reisma, 2009; Nauts, Metzmacher, Verwijmeren, Rommeswinkel, & Karremans, 2012). This explanation was supported by men’s elevated self-reported levels of impression management when they were facing a man (vs. woman) in the study by Karremans et al. (2009).

Thus, the influence of a direct gaze on effort allocation possibly depends on the interpretations about the meaning of the gaze. This is, of course, a hypothetical suggestion, and more empirical evidence addressed directly to test this hypothesis is needed. In addition, our results are limited by the fact that only one woman and one man were acting as storytellers. For example, Karremans et al. (2009) showed that a woman’s attractiveness influences how much her presence contributes to men’s cognitive performance. Thus, in addition to our storytellers’ genders, their other individual characteristics and possible individual differences in their gaze behaviour might have contributed to the gender effects we found.

Surprisingly, among female participants, the effect of gaze direction was found neither on arousal nor on memory performance. Studies reporting enhanced skin conductance responses to direct gaze have included both males and female participants (Hietanen et al., 2008; Nichols & Champness, 1971; Myllyneva & Hietanen, 2015) or only female participants (Pönkänen, Peltola et al., 2011; Pönkänen & Hietanen, 2012), and no gender differences have been reported. In one study only female participants, and not male participants, showed enhanced pupil dilation responses to direct vs. averted gaze (Porter et al., 2006). Pupil dilation has been used as an index of affective arousal, because it varies with SCRs
during affective picture viewing (Bradley, Miccoli, Escrig, & Lang, 2008; Lang & Bradley, 2010), although it has also been associated with cognitive load and processing effort, as it is controlled both by the sympathetic and parasympathetic branches of the autonomic nervous system (Beatty, 1982; Steinhauer et al., 2004). As far as we know, the only previous study showing that females participants’ performance might not be influenced by direct gaze as consistently as male participants’ while performing a memory task was the study by Otteson and Otteson (1980) with primary-school children. No gender differences have been reported in the gaze aversion literature (Doherty-Sneddon et al., 2001; Doherty-Sneddon, et al., 2002; Doherty-Sneddon & Phelps, 2005; Doherty-Sneddon, et al., 2009; Riby, Doherty-Sneddon et al., 2012), although gender effects have not been directly investigated in those studies either. However, it might be that during cognitive tasks, women, compared to men, are less influenced by incidental direct gaze during cognitive tasks, as they generally make more eye contact (Bente, Donaghy, & Suwelack, 1998; Mulac et al., 1987; Whitelock & Scanlon, 1998), and might show better inhibition for distracters in multitasking conditions (Ren, Zhou, & Fu, 2009). Thus, perhaps the female participants could inhibit the effects of the storyteller’s gaze while they concentrated on the task at hand. Another explanation for the result originates from our measure of arousal (skin conductance variability during 1 minute), which was different to those used in previous studies (single phasic SCRs). Female participants, overall, had less variability in skin conductance than male participants; therefore, it is possible that female participants’ autonomic nervous system reactions in different gaze conditions were too subtle to be captured with our measure. According to Boucsein (2012), women, compared to men, tend to show less electrodermal reactivity to sensory stimulation. Altogether, as our result with female participants is not supported by previous studies, we are cautious in drawing conclusions, and more research is needed to see how consistent the results concerning the gender differences are.

In Study II, we did not evaluate to what extent attentional processes might contribute to the effect of gaze on performance; however, they would be worth considering in future studies. Both affective arousal and effort allocation presumably have an effect on attention, which in turn affects performance (see Coull, 1998; Eysenck, 1982; Kelley & Gorham, 1988). Elevated arousal narrows attention to fewer stimulus elements in the environment, reduces the ability to discriminate between relevant and irrelevant stimuli, and increases distractibility (Eysenck, 1982). As a strong internal signal, enhanced arousal might trigger attention towards oneself (Silvia & Gendolla, 2001; Wegner & Giuliano, 1980).
Alternatively, enhanced arousal might promote the processing of the stimulus that is triggering the elevated arousal, and thus, for example, direct gaze might promote face encoding (cf., Hood et al., 2003; Macrae et al., 2002). Attention either towards one-self or the counterpart requires cognitive resources that, in turn, reduce the resources available to the current task. Interestingly, several studies have shown that averting one’s gaze from an instructor’s face is beneficial in cognitively demanding tasks (Doherty-Sneddon et al., 2001; Doherty-Sneddon, et al., 2002; Doherty-Sneddon & Phelps, 2005; Doherty-Sneddon et al., 2009; Doherty-Sneddon et al., 2012; Glenberg et al., 1998; Markson & Paterson, 2009; Riby, Doherty-Sneddon et al., 2012). This has been explained by the cognitive load caused by the processing of facial information during eye contact; thus, averting one’s gaze from an instructor’s face frees attentional and working memory resources to the task at hand. On the other hand, attention to the mouth of an instructor instead of the eyes might improve verbal information processing. Thus, possible differences in gaze behaviour might also contribute to the gender effects that were found. In future studies, measuring participants’ gaze behaviour with eye tracking devices would be useful in evaluating the role of attention allocation on performance together with the effects of arousal.

In Study II, we also investigated whether the belief of being seen by the storyteller modulates the effect of eye contact on arousal and memory performance. This was inspired by previous results showing that the belief of being seen by the person you are looking at, and thus, a possibility for two-way interaction, might be a key factor in eliciting enhanced arousal responses (Myllyneva & Hietanen, 2015), and other results indicating that direct gaze might not have a significant effect on memory performance when participants know that they are not seen by the instructor (Sherwood, 1987). However, contrary to our hypothesis and contradicting previous results, the manipulation of the belief of being seen was realised with a similar deception procedure as in Myllyneva and Hietanen’s (2015) study, and was found to not have an effect on either arousal or story recall. The discrepancy between Study II and Myllyneva and Hietanen’s (2015) results might be explained by methodological differences between the studies. First, the method of analysing the skin conductance responses was different (a single phasic SCR in response to stimuli vs. skin conductance variability during one minute). In addition, in our study, the participants were aware of being filmed by a hidden camera, which might have raised participants’ awareness of being observed (see Govern & Marsch, 2001), and therefore, minimize the differences between the two belief conditions. However, the most interesting
explanation rises from the cognitively demanding task that our participants were performing instead of being passive observers of stimuli as in Myllyneva and Hietanen’s (2015) study. The lack of enhanced autonomic responses to direct gaze in comparison to other gaze directions when using pictorial stimuli (e.g. Donovan & Leavitt, 1980; Joseph et al., 2008; Hietanen et al., 2008; Kylliäinen & Hietanen, 2006; Louwerse et al., 2013) or when participants believe that they are not being seen by other person (Myllyneva & Hietanen, 2015) have been explained by the top-down cortical inhibition of sub-cortically induced autonomic responses in these situations. Interestingly, however, one study using pictorial stimuli found enhanced SCR responses to direct vs. averted gaze. In that study, pictorial direct and averted gaze stimuli were shown incidentally during tasks that were cognitively more or less demanding (Conty et al., 2010). When the task was cognitively demanding, enhanced arousal responses to direct gaze were found. Together with the study by Conty et al. (2010), our results suggest that when cognitive resources are occupied with a cognitively demanding task, the effects of cortical modulation on autonomic responses might be suppressed and enhanced arousal responses to incidentally presented direct gaze might be seen even when a participant knows that he/she is not being seen.

The level of the cognitive demands of the task might also have an influence on whether the belief of being seen has an effect on performance, as implied by a recent study using a belief manipulation similar to Study II. In that study, direct gaze (vs. averted) influenced performance in a cognitively demanding Stroop task similarly in both belief conditions, whereas in a simple visual discrimination task, direct gaze (vs. averted) influenced performance only when participants believed they were seen (Hietanen, Myllyneva, Helminen, & Lyyra, 2016). The effects of direct gaze on arousal responses and a lack of top-down inhibition of these responses when cognitive resources are occupied might contribute both to the findings of Hietanen et al. (2016) and the present findings. As a notable observation, the results of Hietanen et al.’s study (2016) used live faces that differed from a comparable study using pictorial stimuli (Conty et al., 2010); in Hietanen et al.’s study (2016), the influence of direct gaze on performance in the Stroop task was facilitative, i.e. resulting in shorter response times, whereas in a comparable study using pictorial stimuli, the effect of direct gaze (vs. averted) resulted in slower response times. Further research combining psychophysiological measures of arousal and attention with behavioural tasks is needed to clarify how much arousal mediates the effect of gaze in live vs. pictorial conditions under
cognitively more or less demanding tasks, and whether other processes related to effort allocation and/or attention accounted for these differences.

4.3 Atypical orienting to direct gaze in young children with autism

The results of Study III were compatible with the results previously found in healthy adults (Akechi et al., 2013; Myllyneva & Hietanen, 2015), and showed that young children without ASD showed an enhanced heart rate orientation response to dynamic shifts of eye gaze towards direct vs. averted direction. The study expands previous behavioural findings by showing that attention capture by direct gaze is manifested in efficient stimulus detection (Böckler, van der Wel et al., 2014; Conty et al., 2006; Doi et al., 2009; Farroni et al., 2002; Palanica & Itier, 2012; Senju & Hasegawa, 2005; Senju, Hasegawa et al., 2005; Von Grünau & Anston, 1995), and is accompanied by a physiological heart rate orienting response. The deceleration of heart rate is thought to enhance information intake, that is, enhance the deeper exploration of socially salient stimuli (cf. Öhman et al., 2000).

In contrast, as hypothesized, young low-functioning children with ASD did not show a greater heart rate orienting response to direct gaze compared to averted gaze. The task properties were planned such that all the children would easily detect the shift in eye gaze, and as expected, the eye tracking data confirmed that there were no differences between the children with ASD and the control groups in the looking patterns of the eye region. That is, the lack of the orienting response in children with ASD was not explained by a lack of perceptual registration of the eyes. Thus, in addition to the fact that these children seem to lack the typical detection advantage of direct gaze (Senju, Hasegawa et al., 2005; Senju et al., 2003), they do not respond to perceived direct gaze with enhanced physiological orienting, which presumably means that direct gaze lacks social signal value for children with ASD. Compatible with our results, previous results have shown that school-aged children with ASD do not show the enhancement of an attention-related ERP component to direct vs. averted gaze (Senju, Tojo et al. 2005). Together, these results support the hypothesis that children with ASD passively omit signals related to gaze directed at them, which furthers the understanding of diminished eye contact behaviour.

Senju and Johnson (2009b) have proposed in their fast-track modulator model that ASD children might have abnormalities in subcortical structures (e.g. in the
amygdala) and in the circuits between subcortical and cortical structures, and these abnormalities might explain their reduced response to direct gaze. In accordance with this theory, a study using a continuous flash suppression paradigm showed that while typically developing adolescents detected direct gaze faster than averted gaze, adolescents with ASD did not (Akechi et al., 2014). This result indicated that the initial, unconscious processing of direct gaze, which presumably relies on a subcortical route, was not enhanced in ASD adolescents, similar to typically developing adolescents (Akechi et al., 2014). Furthermore, there is evidence showing that functional connectivity between the amygdala and cortical regions (the medial prefrontal cortex, temporoparietal junction, and posterior superior temporal sulcus region) is reduced in adults with ASD (von dem Hagen, Stoyanova, Rowe, Baron-Cohen, & Calder, 2014).

So far, the majority of social cognition research has focused on school-aged high-functioning children with ASD (cf., Itier & Batty, 2009). The older the children are and the more cognitive capacity they have, the more opportunities they have had to learn to cope with their disabilities in different ways. This makes it difficult to make causal interpretations about their difficulties. The present study broadens the understanding of eye contact difficulties in ASD by focusing on young, low-functioning children with autism. The present results provide support for the primary cause for reduced use of eye contact in children with ASD being the passive omission of social signals related to eye gaze rather than elevated, negatively valenced arousal responses leading to the active avoidance of eye contact, as proposed by the hyperarousal theory (e.g. Bowman et al, 2004; Dalton et al., 2005; Hutt & Ounsted, 1966; Skuse, 2003; Tanaka & Sung, 2016). The enhanced arousal response to eye contact that has been found in some previous studies with high-functioning school-aged children with ASD (Kylliäinen & Hietanen, 2006; Kylliäinen et al., 2012; Stagg et al. 2013) might have emerged later in development, for example, due to fewer experiences in eye-to-eye communication or due to anxiety caused by the awareness of social demands related to eye contact. This conclusion is also supported by Nuske et al.’s (2015) results, which did not show differences in pupil responses to eye gaze stimuli between 2–5-year-old children with ASD (both low- and high-functioning) and their age-matched TD controls. It is also good to note that some studies with school-aged high-functioning children with ASD have not found enhanced arousal responses to faces with direct gaze (Joseph et al., 2008; Kaartinen et al., 2012; Louwerse et al., 2013), and some have even found hypoarousal (Riby, Whittle et al., 2012). It should be stressed that hypotheses suggesting the omission and avoidance
of eye contact might not be mutually exclusive. Different subgroups within the autism spectrum (or even the same children in different situations and developmental stages) might respond differently to direct gaze. The data of Study III were limited by a small sample size, which did not allow a further analysis of possible individual differences. Cognitive abilities together with symptom severity could be potential factors influencing physiological responses to eye gaze (Joseph et al., 2008; Kaartinen et al., 2012; Kaartinen et al., 2016; Stagg et al., 2013), as well as influencing the level of atypicalities in attention to faces (Ribu & Hancock, 2009; however, also see Gillespie-Smith, Ribu, Hancock, & Doherty-Sneddon, 2014, which found no effects). Furthermore, responses to facial pictures might be different than those for live faces, as discussed above. Taken together, more research investigating a wide range of developmental stages and children with different degrees of symptom severity in different kinds of experimental setups is needed to fully understand eye contact difficulties in ASD.

Interestingly, although differential heart rate deceleration responses to direct vs. averted gaze have been demonstrated only with live presentation of faces when the participants know that they are seen by the model (Akechi et al., 2014; Myllyneva & Hietanen, 2015), pictorial stimuli with direct vs. averted gaze resulted in enhanced heart rate deceleration responses in Study III in children without autism. There are at least three possible explanations for finding differential HR responses in our study, which were not seen in previous studies using pictorial stimuli (Donovan & Leavitt, 1980; Louwerse et al., 2013; Wieser et al., 2009). First, the dynamicity, that is, the illusion of the gaze shift, might be a factor that promoted similar responses for live faces in previous studies. Second, analysing the HR deceleration response to mere gaze shifts and not to the appearance of face stimuli might have promoted finding differences between gaze directions. Third, young children might respond to pictorial material more robustly than adults. In children, the cortical modulation of autonomic responses might not be as efficient as in adults. Studying older children and adults with a similar task as in the present study would reveal whether the latter explanation is correct. In the future, because HR deceleration responses and SCR responses tend to occur together during the orientation response, investigating SCR responses to pictorial, dynamic gaze shifts would also be interesting.
4.4 Concluding remarks

The present series of studies explored the effects of direct gaze on arousal and attention by using measures of autonomic nervous system activity. First, it was shown that the direct gaze of a live face causes enhanced arousal responses when compared to other gaze directions, and this was observed independently of the length of stimulus duration. Thus, direct gaze increases autonomic sympathetic arousal also when seen only briefly such as in everyday encounters. This result is not only relevant to understanding the effects of eye contact in real-life settings, but also might have practical value in experimental eye contact research, for example, when investigating children or other individuals whose attentional capacity is limited.

Although individual differences in autonomic arousal responses to eye contact were not found in the present study, it would be interesting to further investigate possible personality influences on psychophysiological responses to eye contact with bigger sample sizes containing larger variation in individual differences. Particularly, emotional stability (i.e. neuroticism), which was shown to influence behavioural responses to direct gaze, warrants more research, as it has been associated with social anxiety (Norton, Cox, Hewitt, & McLeod, 1997), which in turn has been indicated to influence autonomic responses to direct gaze (Myllyneva, Ranta et al., 2015; Wieser et al., 2009). Other dimensions of personality besides Big Five personality factors might be worth investigating as well, for example, Gray’s (1991, 1994) behavioural activation system (BAS) and behavioural inhibition system (BIS) sensitivities, which are thought to be neurobiologically based motivational systems underlying behaviour and affect. The gender differences that were revealed in Study II stress the importance of investigating the effects of gender further and counterbalancing both the participants’ and stimulus persons’ genders in future studies.

It was also shown that affective arousal mediates the effect of eye contact on arousal. However, by showing that the mediating effect of arousal was accompanied by a parallel process that was moderated by the storyteller’s gender and had the opposite effect on performance, our results also demonstrated the complicated nature of socio-cognitive phenomena that influence performance. As eye contact has the power to influence not only arousal but also effort allocation and attention, and as all these are presumably top-down modulated by interpretations about the situation, it is clear that predicting whether performance will improve, worsen, or remain unaffected in the consequence of eye contact in
different situations is very challenging. Altogether, however, it is clear that eye contact plays a role in social learning situations.

In addition, the effect of the belief of being seen by eyes that are directed towards oneself on memory performance was investigated. Although no effects for the belief of being seen were found in Study II, it would be interesting to further investigate the effects of direct gaze and the effects of being seen on cognitive performance on tasks with different levels of difficulty in conditions where an instructor is presented live, through video-conferencing equipment allowing two-way interaction, or through videos. Some research comparing live and video-link communication with and without eye contact already exists (Doherty-Sneddon et al., 1997), but more research is needed, especially when considering that video-based communication is becoming increasingly common in education. Moreover, although the belief of being seen has previously been shown to be an important factor in eliciting differential physiological responses to direct vs. averted gaze directions (Myllyneva & Hietanen, 2015), the present results indicated that enhanced responses can also be found when this belief is not fulfilled. First, enhanced arousal responses to direct gaze were found without this belief in Study II, which might be explained by the participants’ performance of cognitively demanding task. Second, an enhanced heart rate orientation response to dynamic pictorial gaze shifts to direct vs. averted gaze was found in children. Because using pictures in experimental studies is very practical and allows better control for the stimuli, it is important to further investigate whether it is the dynamicity of the stimuli or, for example, the age of the participants, that allowed us to find the effects of gaze direction in contrast to other studies using pictorial stimuli.

Finally, the heart rate orientation response was used to investigate eye contact difficulties in children with ASD. It was shown that children with ASD did not respond to direct gaze (vs. averted) with an enhanced heart rate orientation response, whereas their typically developing and developmentally delayed peers did. A lack of readiness to orient and engage attention to direct gaze might lead one to ignore signals that indicate other persons’ intentions to communicate in everyday social situations; thus, it might have far-reaching consequences for the development of social interaction skills. In the future, a growing understanding of the reasons underlying the eye contact difficulties of children with ASD will hopefully help in planning early interventions for relieving their social problems.

Senju and Johnson (2009b) have stated that ‘Eye contact behaviour is an ideal model system to investigate the mechanisms underlying, and the development of, human social interaction and communication, both in typically developing individuals as well as in individuals
Although gaze is only one means of communication between people, eye contact has an important role in building relationships between people and in communicating intentions and emotions. The present studies are based on a long history of eye contact research, and more research is still needed to fully understand the mechanisms and factors affecting the effects of eye contact on cognition and development, and how these effects relate to the relationships between individuals.


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ORIGINAL PUBLICATIONS (STUDIES I-III)
Eye contact and arousal: The effects of stimulus duration

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ABSTRACT

The present study investigated the effect of stimulus duration on skin conductance responses (SCRs) evoked by different gaze directions of a live person. In two separate parts of the experiment, either two fixed stimulus durations (2 s and 5 s) or a participant-controlled stimulus duration was used. The results showed that the eye contact evoked enhanced SCRs compared to averted gaze or closed eyes conditions irrespective of the presentation time. Subjective evaluations of approach–avoidance-tendencies indicated that the direct gaze elicited either approach or avoidance, depending on the participant. Participants who had evaluated a direct gaze-condition as approachable were found to be more emotionally stable than those who had evaluated the same condition as avoidable. In the self-timing condition, averted gaze was looked at longer than direct gaze. Our results suggest that direct gaze, also when encountered only briefly like in every-day social encounters, increases autonomic sympathetic arousal.

1. Eye contact and arousal: the effects of stimulus duration

"Under optimal conditions of interpersonal encounter, the gaze of the other may be experienced as streaming into my whole being - I am filled out and irradiated by it" (Heron, 1970). The quotation from Heron (1970) describes very well how powerful stimulus a direct gaze is for human beings. The importance of the direct eye gaze is reflected, for example, in the special effects direct gaze imposes on attention and other cognitive processes. For example, people are faster to detect a face with a direct than averted gaze (Senju et al., 2005; Von Grünau and Anston, 1995) and direct gaze facilitates facial gender discrimination (Macrae et al., 2002) and identity recognition (Hood et al., 2003). Recent neuroimaging studies have revealed a distributed neural network sensitive to the direction of gaze (for review, see Nummenmaa and Calder, 2009). The amygdala has been suggested to participate in evaluating the salience of the perceived gaze direction, and it has been suggested to play a central role in mediating the affective arousal elicited by the eye contact (Senju and Johnson, 2009). These functions fit with the amygdala’s tasks in regulating affective arousal, in general (Laine et al., 2009; LeDoux, 2000; Williams et al., 2005). For example, direct stimulation of the amygdala has been shown to produce strong skin conductance responses in humans (Mangina and Beuzeron-Mangina, 1996). The enhanced affective arousal elicited by the eye contact is supposed to influence subsequent perceptual and cognitive processing (Senju and Johnson, 2009).

Considering the large number of studies investigating perception of gaze direction, the effects of gaze direction on attention, and the neural mechanisms subserving gaze-related social cognitive processes, there are, perhaps, a surprisingly small number of studies which directly have investigated the effects of eye contact on an observer’s state of arousal. One reason may be related to the fact that the results of those few studies on this issue have not been consistent. On the one hand, there are studies showing that seeing another person’s direct gaze vs. averted gaze results in heightened levels of arousal as measured with the skin conductance responses (Nichols and Champness, 1971), heart-rate (Kleinke and Pohlen, 1971), and EEG alpha-arousal (Gale et al., 1972, 1975). On the other hand, there are also a group of studies which have found only marginal differences (Donovan and Leavitt, 1980) or which have not found any differences at all in autonomic arousal for direct vs. averted gaze in typically developing children and adults (Joseph et al., 2008; Kampe et al., 2003; Kyliläinen and Hietanen, 2006; Leavitt and Donovan, 1979; Martin and Gardner, 1979; Wieser et al., 2009). Recently, Hietanen et al. (2008) suggested that the discrepancy could be related to fact that, in all the studies reporting enhanced arousal to direct gaze, the stimulus person was presented “live”, whereas in all the studies (except the Martin and Gardner, 1979 study) reporting no differences between direct and averted gaze, the face stimuli were presented as pictures (either static or dynamic) on a TV monitor or a computer screen. Hietanen et al. (2008) measured skin conductance responses both when the participants were looking at images of faces on a computer screen, and when they were seeing a live person’s face through a
computer-controlled liquid crystal shutter, and reported no effect of gaze direction on SCR in the picture presentation condition, whereas in the live condition the autonomic responses were significantly larger for the direct than averted gaze.

In the present experiment, we wanted to take a few steps further in the investigation of autonomic responsivity to another person’s gaze. In addition to investigating the effects of gaze direction on autonomic arousal, we wanted to find out how the length of the eye contact affects autonomic responses. Argyle and Dean (1965) proposed that for any pair of people there is an optimal level of intimacy that is composed by eye contact, physical proximity, intimacy of topic, amount of smiling, etc. It has been shown, for example that decreasing the physical distance between two participants engaged in eye-contact increases the skin conductance responses (McBride et al., 1965) and EEG arousal (Gale et al., 1975). Now, besides the distance between people, duration of eye contact is another typical factor to vary in everyday social encounters. In an early study by Mobbs (1968), where participants discussed about a picture with another person, the average length of the single periods of eye contacts varied from 1.7 to 3.6 s, according to the personality characteristics of the participants. According to Argyle (1981), when two people are having a conversation on an emotionally neutral topic at a distance of six feet, the length of eye contact is 1.5 s on average.

In the previous physiological studies by Hietanen et al. (2008) and Nichols and Champaign (1971), where enhanced SCRs for direct vs. averted gaze were reported, the stimulus presentation times were 5 s and 10 s, respectively. Thus, relative to the duration of eye contact in more natural situations (Mobbs, 1968; Argyle, 1981), the presentation time of the gaze stimuli in these laboratory studies can be considered as unusually long. It should also be noted that the stimulus presentation times were equal between the aforementioned studies using live models and reporting differences in autonomic responses to direct vs. averted gaze (range 5–18 s) and studies presenting pictures of faces and reporting no effects of gaze direction (range 4–20 s). In fact, already Donovan and Leavitt (1980) raised the possibility that unconventionally long stimulus durations may account for increases in physiological response to eye contact, and recently Senju and Johnson (2009) also discussed a possibility that the autonomic arousal to eye contact reported in previous studies might be restricted to the prolonged presentation of the stimuli. Thus, in this study, we investigated, how the duration of the stimulus presentation affects the SCRs to gaze stimuli. In an earlier study, Schaeffer and Patterson (1980) showed that a confederates’ lengthened direct gaze (2 s vs. 10 s) in a group session resulted in an increase in subjects’ arousal as measured with self-ratings and performance measures (performance in a complex cognitive task was supposed to deteriorate with increased arousal). However, to the best of our knowledge, there are no previous studies investigating the effect of the length of eye contact on arousal as measured with psychophysiological indicators.

Taken together, in the present study, we measured skin conductance responses to seeing another person with a direct and averted gaze. We also included a closed eyes (no eyes) condition in our design. Alongside with averted gaze, closed eyes offer one more natural control condition where the participant is not a target of another person’s attention. To increase the naturalness and the ecological validity of the experiment, the stimulus faces were presented “live” through a computer-controlled liquid crystal shutter. Another objective of the present study was to investigate the possible effects of the stimulus presentation time on the arousal responses. Therefore, we presented the stimuli with a short (2 s) and long (5 s) duration, in the first part of the experiment, and, in the second part of the experiment, we allowed the participants to control the opening and closing of the electronic shutter themselves. Additionally, this way, we also acquired behavioral data of the subjectively preferred looking times for direct and averted gaze. On the basis of the previous research, we predicted that seeing a direct gaze (eye contact) will result in higher SCRs than seeing an averted gaze or seeing a face with closed eyes. We hypothesized that the longer presentation time of the stimuli would result in larger SCR than the shorter one. In Hietanen et al. (2008) study, the affective valence ratings showed that a live face with an averted gaze was evaluated as more positive than a face with a direct gaze. Based on these findings, we predicted that, in the self-controlled condition, the participants would choose to look the direct gaze for shorter time than the averted gaze. In addition to measuring autonomic skin conductance responses, we also measured subjective approach–avoidance evaluations in different gaze conditions. There is recent electrophysiological evidence showing that seeing another person’s direct gaze elicits relative left-sided frontal EEG activation, indicative of a tendency to approach, whereas averted gaze activates right-sided frontal asymmetry associated with avoidance (Hietanen et al., 2008). Thus, regarding the subjective evaluations of approach–avoidance–tendency, we predicted that the participants would evaluate the direct gaze as more approachable than the averted gaze or the closed eyes condition. Finally, we were interested in investigating whether individual differences in personality modulate the measured physiological and behavioral responses. The personality characteristics of the participants were investigated with a Finnish test based on the five-factor model of personality (e.g. McCrae and Costa, 2008; Pervin and John, 1997) and measuring extraversion, agreeableness, conscientiousness, emotional stability (inverse to neuroticism) and openness to experience.

2. Methods

2.1. Participants

The participants were 33 adults (18 females, mean age 22.8 years, range 19–43) who gained a course credit for participation. The participants had normal or corrected-to-normal sight. Informed and written consent was obtained from each participant. Data from one male participant were discarded from all the analyses because of technical problems in recordings. Additionally, two (one female) participants were discarded from the analysis of part 1 and four participants (one female) were discarded from the analysis of part 2 because of the number of acceptable SCRs was too small for the corresponding conditions. The analysis of part 1 was based on data from 30 participants and the analysis of part 2 is based on the data from 28 participants. Additionally, one participant did not return the personality questionnaire.

2.2. Materials and procedure

The facial stimuli were the faces of two female experimenters collecting the data (T.M.H. and S.M.S.). The identity of the stimulus faces was approximately counterbalanced across the male and female participants (T.M.H.: 8 males, 7 females; S.M.S.: 7 males, 11 females). The faces bore a neutral expression. However, to avoid a sullen, negative face, the models maintained a very slight muscle tonus in their lower faces. The models kept their faces as motionless as possible. They tried to avoid eye blinks, but when necessary, eye blinks were allowed to occur. The faces were presented through a 40 cm × 30 cm liquid crystal (LC-TEC Displays Ab) shutter attached to a white frame on the table between the model and the participant. The participant was seated at a distance of 70 cm away from the frame, and the model’s face was 30 cm away on the other side of the frame, at the same height as the subject’s face. The voltage sensitive LC-shutter switched between opaque and transparent states within an overall speed of 3 ms. Stimulus presentation was controlled by Neuroscan Stim software (Neuroscan, El Paso, Texas, USA) running on a desktop computer.

On arrival to the laboratory, the participant was introduced to the laboratory, the general procedure was described, and an informed consent was obtained. After this, the participant was prepared for the skin conductance measurements. All this was done by the experimenter who was going to be the model. The experimenter kept the atmosphere calm and rather informal by chatting friendly with the participant, in order to help the participant to feel her/himself as comfortable as possible. None of the participants were acquainted with the experimenter before the experimental session to ensure that the relationship between the model and the participant would be as similar as possible for all experimental sessions. The electrodes (Ag/AgCl; diameter 8 mm) were coated with paste and attached to the palmar surface of the medial phalanges of the index and middle fingers on the participant’s left hand. The signal was acquired with a GSR amplifier supplying constant-voltage AC excitation (22 mV).
(ADInstruments). Power Lab 400 equipment was used for the SCR measurements and the data collection was controlled by Power Lab Chart v3.5 computer program running on a Power Macintosh 7100/80 computer. Each participant was instructed to each session to detect activity in the range of 0–40 μS. The sampling rate was 100/s.

The experiment was divided into two parts. In the first part, the participant saw two blocks of 18 trials, where the model’s gaze was either direct (0 ms or right), or the eyes were closed (6 trials in each condition). The averted gaze of 30 ms was accomplished by looking at the certain points on the parting behind the participant. The order of the trials was pseudo-randomized so that there were no more than two consecutive trials of the same type. In one block, the presentation time was 2000 ms (ISI varied randomly from 21 to 25 s) and in another it was 5000 ms (ISI 18–22 s). The order of the blocks was counterbalanced across the participants. During the ISI, the shutter remained opaque. A short (500 ms) and soft audio signal was presented through the speakers 5 s before the start of the next trial to direct the participant’s attention to the shutter. The participant was instructed to look at the stimuli, and after the shutter was closed, to make a subjective evaluation about his/her tendency to approach (“evaluate whether you would like to approach or make a contact with the person, for example, by saying something”) or avoid (not to make a contact with) the model. The evaluations were made with a slide potentiometer fixed into a small box. A similar method for measuring approach–avoidance tendencies was used in a study by Hietanen et al. (1998). The participants had the box in their lap comfortably within the arm’s reach. The lever of the potentiometer moved approximately 4 cm forwards or backwards from the center position. The end that was closer to the subject was labeled “approach” and the other end was labeled “avoid.” With the increase of the lever movement, the participant could indicate the strength of his/her tendency to approach or avoid the model. The participant was able to use the device with slight movements of his/her fingers, so that the motor activity would not disturb the SCR measurements. Also, to ensure that the motor responses did not affect the SCR measurements, the participant was instructed to make the response after the shutter was closed. The output voltage of the potentiometer was registered with the same equipment that was used to measure SCR.

In the second part of the experiment, direct and averted gaze stimuli were presented. Eight trials were presented in pseudo-randomized order, 4 trials in both conditions. The model and the stimulus conditions were otherwise the same as in the first part of the experiment. The participant was instructed as follows: “The time that different people feel it natural to look at another person’s face in different situations varies. Now, we want to measure the time you feel it is natural to look at the face in the present situation. There are no right or wrong answers. This is not a contest of who can stare the longest at the other person, the looking-time can also be quite short.” On each trial, the model told the participant when he/she was allowed to open the shutter. In this way, the model could ensure that the ISI between consecutive trials was long enough (about 20 s), and she could also prepare herself for the next gaze condition (like in the first part of the experiment, the model was following a script for the gaze conditions). The participant was instructed to open the shutter after hearing the model saying it was possible (“ready”) and close it whenever he/she felt it was natural. The opening and closing of the shutter was made with a switch. The switch box was in the participant’s lap. The voltage changes resulting from the opening and closing of the shutter (allowing measurement of the looking-times) were again registered with the same equipment registering the SCR.

After the experiment the participant was given the PK5 personality questionnaire (Pediatriensyntyma, 2007) which was asked to be completed at home, and to be sent to the researcher afterwards. PK5 is a Finnish personality test based on the Big Five – personality factors [extraversion, agreeableness, conscientiousness, emotional stability (inverse to neuroticism) and openness to experience]. The questionnaire consists of 150 claims to which the participant answers on a 5-point Likert-scale (1 agree perfectly, 5 don’t agree at all). Alpha reliabilities of the factors ranged from .85 to .95 in the standardization study (Pediatriensyntyma Kustannus Oy, 2007).

2.3. Data analysis

The skin conductance response (SCR) was defined as a maximum amplitude change from the baseline level (at the stimulus onset) during a 4-s time period starting after 1 s from the stimulus onset. If there was more than 0.1 μS amplitude change before 1 s after stimulus onset, the trial was rejected, because that response can be considered to be too early to be elicited by the gaze stimulus (Dawson et al., 2000). 14.8% of all the trials were eliminated on the basis of this criterion or on the basis of technical difficulties in recordings (direct gaze condition: 17.0%, averted: 14.3%, closed eyes, 12.8%). After removal of eliminated trials, if a participant had less than a half of the trials left in each condition, the data were rejected from subsequent analyses. The data were averaged in each condition for each participant, including those trials without a measurable response as a zero response. The data were averaged in each condition for each participant, including those trials with maximum amplitude below 0.01 μS as a zero response. This method of calculation results in the galvanic skin conductance signal being treated as a binary variable, where increases in conductance are treated as positive events and decreases are treated as negative events. The provisions of that model’s gaze was either direct, averted or, at home, left that combines response size and response frequency (Dawson et al., 2000). To normalize the data for the statistical analyses, a log transformation [log(SCR + 1)] was performed.

For the subjective evaluations of approach and avoidance in the first part of the experiment, the voltage changes from the potentiometer were transformed into maximum value from 21 to 25 s through 0 to +2 (approach). The evaluation score was defined as the maximum change from the prestimulus level. The approach–avoidance scores were analyzed by calculating the average in each condition for each participant. For the looking-time data in the second part of the experiment, the looking-time differences were calculated from the voltage changes related to the opening and closing of the shutter. The looking times were averaged in both conditions for each participant.

The statistical analyses were performed with PASW Statistics 18. A Greenhouse–Geisser correction procedure was applied when appropriate, in which case the epsilon value is reported for the sake of brevity, uncorrected degrees of freedom are reported. For all multiple comparisons, LSD correction was performed.

3. Results

3.1. Part 1 (fixed stimulus duration)

A two-way analysis of variance (ANOVA, repeated measures) was performed on the SCR data, having Gaze (direct, averted, eyes closed) and presentation time (2000 ms, 5000 ms) as independent variables. The ANOVA indicated a main effect of Gaze, F(2, 58) = 17.1, p < .001, ηp² = .371, ε = .775. There was no significant main effect of presentation time, and the Gaze and presentation time was not significant either. Pairwise comparisons (LSD) showed that the SCR for direct gaze (M = 0.37 μS) was larger than SCR to averted gaze (M = 0.20 μS, p < .001) and to closed eyes (M = 0.19 μS, p < .001). The difference between SCRs to averted gaze and to closed eyes was not significant. To ensure that there were no differences in the SCRs between the two presentation times, t-tests (paired samples) were performed for direct, averted, and closed eyes conditions separately. The results showed that, indeed, the presentation time had no effect on the SCRs in any of the gaze conditions.1 The results are presented in Fig. 1A.

The subjective evaluations of approach–avoidance–tendency [range: −2 (avoidance) to +2 (approach)] were analyzed with a similar two-way ANOVA as above. The main effect of Gaze was significant, F(2, 58) = 3.4, p = .048, ηp² = .105, but again, the main effect of presentation time or the interaction between the presentation time and Gaze were not significant. The pairwise comparisons showed that the averted gaze (M = 0.04) was judged as more approachable than the closed eyes (M = −0.50, p = .007). The approach–avoidance evaluations for direct gaze condition (M = −0.07) did not differ significantly from the other two conditions (see Fig. 1B). Correlations calculated between the approach–avoidance evaluations and the mean SCRs in each gaze condition showed no association between these subjective evaluations and the autonomic responses (direct gaze: r = −.10, n.s., averted: r = −.17, n.s., closed eyes: r = .05, n.s.).

The correlations between the personality factors and the physiological and behavioral measures revealed some statistically significant results, but these seemed to be sporadic and difficult to interpret in a meaningful way. Skin conductance responses to closed eyes correlated with extraversion (r = −.43, p = .020), and the approach–avoidance–evaluations of averted gaze correlated with openness to experiences (r = .41, p = .027) and with conscientiousness (r = −.45, p = .015).

1 To exclude the possibility that the used time window for analyzing the SCR (1–5 s post-stimulus) was too short to capture the SCR with the longer stimulus presentation time, the results were also analyzed by using a 1–8 s window for the block with 5000 ms stimulus duration. In this case, the response had to start within the first 4000 ms (cf. Turpin et al., 1999; Joseph et al., 2008). Also, if the SCR had two peaks within the analysis window, the first one was considered as a response, as we suspected that the second peak might represent a SCR to participant’s approach–avoidance evaluative response. Importantly, the results showed, again, no effect of presentation time.
A closer inspection of the data revealed that about a half of the participants had evaluated the direct gaze as approachable (average rating value >0, n = 13), while the other half had evaluated it as avoidable (average rating value <0, n = 16). Now, there is an annoying possibility that this classification result reflects nothing else but randomly given evaluative responses. To inspect this possibility, t-tests were performed to compare these two groups of participants on the personality dimensions of PKS. The analyses indicated a significant difference between these groups on emotional stability dimension, t(27) = 2.4, p = .022. Participants who had evaluated the direct gaze as approachable were more emotionally stable (n = 13, M = 110.6) than those who had evaluated direct gaze as avoidable (n = 16, M = 94.9).\(^2\) Moreover, this finding was specific to evaluations regarding the direct gaze. Similar analyses upon groupings based on ratings for averted and closed eyes showed that there were no significant differences on emotional stability between those participants who had evaluated the averted gaze as approachable (n = 14, M = 101.9) vs. avoidable (n = 15, M = 101.9) or who had evaluated the closed eyes as approachable (n = 9, M = 97.1) vs. avoidable (n = 20, M = 104.1) (Table 1).

### 3.2. Part 2 (self-controlled stimulus duration)

A one-way analysis of variance (ANOVA) was performed on the SCR data, having Gaze (direct vs. averted) as an independent variable (see Fig. 2A). Again, the ANOVA indicated a main effect of Gaze, F(1, 27) = 27.5, p < .001, \(\eta^2_p = .504\). Direct gaze (M = 0.87 \(\mu\)S) triggered stronger SCRs than did averted gaze (M = 0.52 \(\mu\)S). For the looking-time data, the ANOVA indicated a main effect of Gaze, F(1, 27) = 12.4, p = .002, \(\eta^2_p = .315\). On average, participants looked longer at the averted (M = 5.5 s) than direct gaze (M = 4.0 s). The results are shown in Fig. 2B. The correlation between participants’ mean looking-times and respective SCRs was analyzed. These analyses showed that the autonomic arousal was not related to the looking-times for either the direct (r = .15, n.s.) or the averted gaze (r = -.09, n.s.).

For the 27 participants who had SCR results from both parts of the experiment, the results from part one and part two were compared. In part 1, the data were averaged across presentation times. A two-way ANOVA was performed having Gaze (direct vs. averted) and Part of the experiment as independent variables. As expected, the ANOVA indicated a main effect of Gaze, F(1, 26) = 50.0, p < .001, \(\eta^2_p = .658\), but also a main effect of Part of the experiment, F(1, 26) = 83.0, p < .001, \(\eta^2_p = .761\). The SCRs were greater in the self-controlled (M = 0.72 \(\mu\)S) than fixed (M = 0.24 \(\mu\)S) timing condition. The interaction was not significant.

### 4. Discussion

The main purpose of the present study was to investigate, first, the effects of gaze direction on autonomic arousal and, second, whether the length of the stimulus presentation has an influence on the autonomic arousal. A special feature of the present experiment was that, like in our previous study (Hietanen et al., 2008), we used a live person as a stimulus. In part 1 of the experiment, two different stimulus durations (2 s and 5 s) were presented in two separate blocks. We anticipated that as the participants were able to expect that, within a block, they would be seeing the faces repeatedly for a short or long period (subjectively, 5 s was likely to feel quite a long time), the skin conductance responses, at least for direct gaze, would be pronounced in the block with longer stimulus duration. However, the results showed that direct gaze evoked higher skin conductance responses (SCRs) than averted gaze and/or closed eyes conditions, but independent of the stimulus presentation time. There was no difference in the SCRs for short (2 s) and long (5 s) stimulus presentation times. SCRs between averted gaze and closed eyes conditions did not differ either suggesting that a mere presence of the eyes is not enough to evoke enhanced arousal. Thus, the present study provides support for a view that direct gaze specifically, also when encountered only briefly like in every-day social encounters (cf. Argyle, 1981; Mobbs, 1968), increases autonomic sympathetic arousal. For research on the field,
the present results may have some practical applicability, as they show that the stimulus duration needs not to be very long when investigating autonomic responses to eye contact.

In part 2 of the experiment, where the participants were asked to control the presentation time of the stimuli themselves, direct gaze again resulted in greater SCR than the averted gaze. Interestingly, the overall SCRs were considerably greater than in part 1. This result becomes even more interesting considering that some habituation of SCR could have been expected as all the subjects performed part 2 after part 1. It is tempting to speculate that the participants’ power to control the looking time may have enhanced their role as an active partner in the interaction, although in a very simplified manner, and this change in the social condition increased the overall autonomic responsivity. This could also be a result of some methodological applicability, worth of considering in further studies, in order to evoke strong autonomic responses.

As predicted, the participants had shorter looking-times for direct than averted gaze. This prediction was based on our previous research (Hietanen et al., 2008) showing higher valence ratings for averted than direct gaze. An interesting possibility is that the shorter looking times for direct vs. averted gaze are related to enhanced arousal for direct vs. averted gaze. It has been proposed that the reason for cutting of the prolonged eye contact might be to reduce the tension evoked by eye contact (Argyle, 1981; Ellsworth et al., 1972; Ellsworth and Langer, 1976; Field, 1981). However, in the present data, the magnitude of SCRs did not correlate with the looking times. Thus, the present study did not provide evidence that the level of arousal would have influenced the length the participants choose to view the direct and averted gaze.

In part 1 of the experiment, the participants also made subjective approach–avoidance evaluations regarding the stimuli. The results showed that, on average, the averted gaze was judged as slightly approachable, whereas the direct gaze and closed eyes were evaluated as avoidable. Only the evaluations between averted gaze and closed eyes were significantly different. However, a more detailed inspection of the results showed that there was a large variation between the participants in the evaluation of the direct gaze – about a half of the participants had evaluated the person looking directly at them as approachable, whereas the other half would have rather avoided the person with a direct gaze. Measurements of the participants’ personality characteristics provided some evidence that these might be related to participants’ approach–avoidance evaluations. Those participants who had evaluated direct gaze as approachable were emotionally more stable (more calm and self confident) than those who had evaluated it avoidable. This association was found only for the evaluations regarding the direct gaze, and not for the evaluations regarding the averted gaze or closed eyes. The evaluations regarding the approach–avoidance tendency were not associated with the strength of the skin conductance responses.

In Hietanen et al. (2008) study, where the experimental setting was comparable to that of the present study, the frontal EEG asymmetry measurements suggested that direct and averted gazes were associated with the brain activity indicative of approach and avoidance, respectively. Now, rather than suggesting that direct and averted gaze elicited differential approach–avoidance tendencies between the present study and that by Hietanen et al. (2008), it is more likely that these seemingly contradictory results reflect the fact that the measurements of frontal EEG asymmetry and self-evaluations of approach–avoidance-tendencies might not correlate. For example, self-reported intensity of emotion does not correlate with the degree of approach or withdrawal motivation as measured with frontal EEG asymmetry (Harmon-Jones et al., 2006). There are also studies of motivation reporting differential results between implicit and self-attributed measures of motivational dispositions (for review, see McClelland et al., 1989; Robinson et al., 2009). Also, future studies should investigate whether the personality characteristics of the participants could have an influence on the approach–avoidance-related frontal EEG activity.

The results showed no effect of the eye contact duration on self-evaluated approach–avoidance-tendency. Recently, Kuzmanovic et al. (2009) showed that the likeability of an animated stimulus face was evaluated higher when the duration of the direct gaze increased. This result may seem to be at odds with the present results. However, besides measuring different dependent variables, a major difference between Kuzmanovic et al. (2009) study and the present study is that in Kuzmanovic et al. (2009) study an animated stimulus face first shifted her/his eyes from averted position to direct and then back to averted position again, whereas in our study a person was constantly looking at the eyes of the participant. Gaze shifts signal changes in the attention of the other person, and his/her alternate attentional engagements and engagements may modulate the evaluative judgments the perceiver makes (Mason et al., 2005). In a situation where the other person first engages his/her attention to you and then turns the gaze away, the length of the direct gaze might signal more about how interested the other person is in you, compared to a situation where the length of the constant eye contact is externally determined by the computer opening and closing an LC window, and when the other person does not seem to be determining the length of the eye contact herself/himself. It must also be noted that, in the present experiment, all the trials in one block had the same stimulus

![Fig. 2. Data from part 2 of the experiment: mean SCRs (A) and looking times (B) to straight and averted gaze. Error bars indicate standard error of the mean.](image-url)
duration which might have resulted in that the duration of the eye gaze did not have an influence on evaluations. The participants probably based their judgments on the most salient differences between the consecutive trials within the blocks, that is, whether the person had a straight gaze, averted gaze, or closed eyes, concealing the possible timing effects between the blocks. In everyday encounters, interpretations of the meaning of another person's direct eye gaze and decisions about how to respond to it are likely to be a complex process, influenced by an interaction of a great variety of variables, including the duration, gaze shifts (Mason et al., 2005), facial expression (Jones et al., 2006), sex (Conway et al., 2008), dominance, (Main et al., 2009) and attractiveness (Kleinke, 1986). Recently, Kuzmanovic et al. (2009) showed that increasing the duration of direct gaze increased neural responses in the medial prefrontal cortex including orbitofrontal and paracingulate regions, which have been previously associated with higher order social cognitive processes such as mentalizing or outcome monitoring.

As noted above, the present results demonstrated that, in an ambiguous experimental situation, another person's direct gaze elicited subjective approach responses in some participants and avoidance responses in others, and that these groups differed in emotional stability. These findings encourage further research targeted on the association between responses to eye contact and individual differences in personality. For example, the effects of social anxiety on responses to eye contact have already raised interest. Self-reported avoidance of the eye contact has been shown to be related to social anxiety (Schneier et al., 2011) and heart rate responses to direct vs. averted gaze are differential in groups of high, moderate and low social anxiety (Wieser et al., 2009). It is worth noticing that persons, who score low on emotional stability (and who, in our study, were more likely to respond to the eye contact with avoidance), are also more likely to experience feelings of anxiety than those who score high on the same dimension (e.g. Pervin and John, 1997). Also personality dimension of extraversion (Mobbs, 1968; Kendon and Cook, 1969; Wiens et al., 1980) and characteristics such as shyness (Iizuka, 1994) and dominance (Kalma, 1992) have been related to the gaze behavior in previous research. In future studies, having a larger variance in personality measures than in the present study, might reveal more associations between personality features and physiological and behavioral responses to eye contact.

Another interesting topic for future studies is the effect of facial expressions and effects of facial features on autonomic responses to gaze direction. In the present study, our models bore a relatively neutral expression on their face, but perception of facial expressions and gaze direction have been shown to interact (e.g., Adams and Kleck, 2003, 2005; Lobmaier et al., 2008; N'Diaye et al., 2009) even at the automatic level of processing (Milders et al., 2011). Hence, it would be worthwhile to investigate whether the enhanced autonomic arousal to eye contact over averted gaze is observed also in the context of emotional facial expressions and whether the nature of facial expression modulates the size of this enhancement. Also, there are studies showing that facial features of dominance (Jones et al., 2010a,b) and sexually dimorphic cues in opposite-sex pairs (Jones et al., 2010a,b) modulate automatic responses to gaze cues. These kinds of facial features might also interact with behavioral responses and autonomic arousal evoked by different gaze directions.

A limitation of our study was that we had females only as stimulus persons. For example, in Donovan's and Leavitt's (1980) study, the male faces elicited greater skin conductance responses than female faces, and the heart rate results were also influenced by both the perceiver's sex and the match between the stimulus person's and perceiver's sex. Therefore, future studies should consider the possible effects of the perceiver's and the stimulus person's sex on physiological and behavioral responses to eye contact. In the present study, our experimental procedure included an evaluation task (approach–avoidance) and it is possible that the cognitive processes associated with this task might have had an influence on the skin conductance responses. However, as the participants performed the evaluation after every trial, the possible influence should be the same across all gaze conditions. Moreover, inclusion of an evaluation task guaranteed, at least to some degree that all the participants were orienting to the situation in a similar way and were going through similar cognitive processes. Finally, it must be noted that the present results can be generalized to adult participants only. Previously, Skuse (2003) has suggested that eye contact may elicit an instinctive fear-response that is based on phylogenetically ancient subcortical neural system, but that adult humans are able to control the functioning of this system with the neocortex (including frontocortical circuits) inhibitory pathways. Considering that the prefrontal cortex is one of the last brain regions to mature (for review, see Casey et al., 2000), an interesting issue for future studies is to investigate whether young children exhibit pronounced autonomic responses to eye contact compared to adult participants.

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**References**


Learning under your gaze: the mediating role of affective arousal between perceived direct gaze and memory performance

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Abstract Previous studies have shown that cognitive performance can be affected by the presence of an observer and self-directed gaze. We investigated whether the effect of gaze direction (direct vs. downcast) on verbal memory is mediated by autonomic arousal. Male participants responded with enhanced affective arousal to both male and female storytellers' direct gaze which, according to a path analysis, was negatively associated with the performance. On the other hand, parallel to this arousal mediated effect, males' performance was affected by another process impacting the performance positively and suggested to be related to effort allocation on the task. The effect of this process was observed only when the storyteller was a male. The participants remembered more details from a story told by a male with a direct vs. downcast gaze. The effect of gaze direction on performance was the opposite for female storytellers, which was explained by the arousal-mediated process. Surprisingly, these results were restricted to male participants only and no effects of gaze were observed among female participants. We also investigated whether the participants' belief of being seen or not (through an electronic window) by the storyteller influenced the memory and arousal, but this manipulation had no effect on the results.

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Introduction

Social psychologists noted already in the late twentieth century that the presence of an observer affects one’s performance, either by enhancing or impairing it (so-called social facilitation effect, see for example reviews by Zajonc, 1965; Bond & Titus, 1983; Aiello & Douthitt, 2001). In his review, Zajonc (1965) suggested, though not relying on strong empirical evidence, that the increase in general arousal that is caused by the presence of others would be an explanation for this effect. Since then, several attempts were made to find evidence for this theory, but the findings were inconsistent due to, for instance, methodological problems, or task and situational variables (see review by Bond & Titus, 1983; Kushnir, 1981). Nevertheless, in the current theories, arousal has remained as a potential contributor in the social facilitation effect (e.g., Uziel, 2007; Aiello & Douthitt, 2001). In the present study, our aim was to find empirical evidence for the mediating role of arousal in verbal memory encoding during the physical presence of an
information-giving person. Moreover, we investigated not only the effect of another person’s presence on memory performance but also, more specifically, whether this effect is due to being in the focus of the other person’s attention.

Eyes convey important information about another person’s focus of attention, mental state, and intentions. A self-directed gaze signals another person’s potential interest for social interaction which might be relevant to the perceiver’s own wellbeing (Kleinke, 1986). Considering this, it is not surprising that direct eye gaze captures (Böckler,Wel, & Welsh, 2014; Conty, Tijus, Hugueville, Coelho, & George, et al., 2006; Doi, Ueda, & Shinohara, 2009; Senju, Hasegawa & Tojo, 2005; von Grünau & Anston, 1995) and holds (Palanica & Itier, 2012; Senju & Hasegawa, 2005) visual attention more efficiently than other gaze directions. Direct gaze has been shown to exert an effect on subsequent cognitive processing of other information conveyed by the face. It has been shown that gender discrimination is faster when the pictured person’s gaze is direct rather than averted (Macrae, Hood, Milner, Rowe, & Mason, 2002; however, for opposite results, see Vuilleumier, George, Lister, Armony, & Driver, 2005). Also, faces presented with a direct gaze are remembered better in a surprise memory test than faces presented with an averted gaze (Hood, Macrae, Cole-Davies, & Dias, 2003).

In addition to influencing face-related information processing, perceived direct gaze seems to influence cognitive processing even more generally. For example, several studies have found positive effects of direct gaze on shortterm memory performance in remembering word/number sequences (Falck-Ytter, Carlström, & Johansson, 2014; Fry & Smith, 1975; Kelley & Gorham, 1988), although contradicting results also exist suggesting that in some circumstances direct gaze of an examiner might have a negative effect on performance in similar tasks (Goldfarb, Plante, Brentar, & DliGregorio, 1995; Nemeth, Turcsik, Farkas, & Janacsek, 2013). Other studies have investigated the effect of direct gaze on verbal episodic memory performance. Otteson and Otteson (1980) measured primary school children’s learning during storytelling and found that those boys that were looked at during the storytelling remembered the story better than those who were not looked at during the same session. However, among girls, the direct gaze enhanced the learning of an easy story while impairing the recalling of a more difficult story. Sherwood (1987) showed in five different studies with adult participants that direct gaze had a positive effect on learning both in a dyadic and in a classroom situation. Finally, in a study by Fullwood and Doherty-Sneddon (2006), adult participants remembered more details from a presentation mediated through videoconferencing equipment when the person at the video looked at the camera compared with not looking at the camera.

The effect of direct gaze on performance has been explained by attentional processes, suggesting that direct gaze helps to retain attention in the task (e.g., Otteson & Otteson, 1980; Sherwood, 1987), or alternatively, it might be a source of distraction, competing with the limited cognitive resources together with the task at hand (Goldfarb et al., 1995; Nemeth et al., 2013). Also, it has been suggested that socio-cultural interpretations of the message carried by a counterpart’s gaze direction might account for the effect of gaze. For example, direct gaze can be interpreted as a sign of approval or disapproval, affecting motivation (Otteson & Otteson, 1980). It has also been suggested that physiological arousal induced by eye contact could play a role in the effect of direct gaze on performance, perhaps by influencing the above-mentioned social and cognitive processes, especially attention (Falck-Ytter et al., 2014; Kelley & Gorham, 1988).
Several studies have shown that seeing another individual’s direct eye gaze, compared with averted, results in enhanced arousal responses (Nichols & Champness, 1971; Kleineke & Pohlen, 1971; Gale, Lucas, Nissim, & Harpham, 1972; Gale, Spratt, Chapman, & Smallbone, 1975; Helminen, Kaasinen, & Hietanen, 2011). Arousal has been associated to performance already in the early twentieth century by the classic Yerkes–Dodson law proposing an inverted U-shape relationship between arousal and performance (see e.g., Eysenck, 1982). According to this law, performance improves with increased levels of arousal up to a point after which performance starts to deteriorate with increasing levels of arousal. More recently, it has been shown that the relationship between arousal and performance is more complicated than this, and it is affected, for example, by task requirements and the way of defining and quantifying arousal (Boucsein, 2012; Eysenck, 1982). Instead of a unidimensional continuum of general arousal, human nervous system seems to include several arousal systems with different neurophysiological underpinnings (Boucsein, 2012). Nevertheless, given this background, it seems reasonable to assume that the arousal can mediate the effect of direct gaze on performance. In the present study, our focus is on autonomic, affective arousal, regulated by subcortical structures, especially the amygdale (see e.g., Boucsein, 2012; Laine, Spitler, Mosher, & Gothard, 2009; Lang & Bradley, 2010).

The effect of gaze on arousal has been suggested to rely on fast and automatic subcortical route, which can be activated even by visual stimuli with low-level properties representing faces and direct gaze (Senju & Johnson, 2009). However, our recent studies (Hietanen, Leppänen, Peltola, Linna-aho, & Ruuhiala, 2008; Myllyneva & Hietanen, 2015; Pönkänen, Peltola, & Hietanen, 2011) have indicated that the effect of eye contact on arousal is not solely a result of bottom-up visual processing of self-directed eyes, but arousal responses are strongly modulated by top-down cognitive processes. According to the studies by Hietanen et al. (2008) and Pönkänen et al. (2011), the arousing effect of direct gaze was evident in a situation where the other person was met face-to-face, but not when seeing a picture of the person’s face on a computer monitor. The authors suggested that this might be related to awareness of being seen by another person. The critical influence of the awareness of being seen by another person was more recently confirmed in another study where the participants were always faced by another person, but the participants either knew that the other person was also able to see them or they were deceived to believe that the other person could not see them (Myllyneva & Hietanen, 2015). The latter condition was realized by leading the participant to believe that a half-silvered mirror was positioned between the stimulus person and the participant. Thus, in both conditions, the participants’ view of the other person was exactly the same, the only difference being whether the participant thought that the other person could see him/her or not. The results showed that the eye contact enhanced arousal compared with averted gaze, but only when the participant knew that he/she was seen by the stimulus person. Interestingly, however, Conty et al. (2010) demonstrated that it is possible to find greater arousal responses to direct vs. averted gaze also with presenting pictures of faces, if the pictures are presented incidentally to a cognitively demanding task. Authors explained this using Senju and Johnson’s (2009) fast-track modulator model. In situations where cognitive resources are available, cortical pathways might inhibit the arousal response mediated by the subcortical route. Instead, when the cognitive processes are busy in other tasks, cortical inhibition is lacking and
incidentally presented eyes can elicit an autonomic arousal response.

The studies cited above prompt one to ask whether the effects of other person’s direct gaze (either facilitative or impairing) on performance are restricted to the situations where participants know that the other person sees them. This is not the case, of course, when participants see a person on a video. In a study by Sherwood (1987), the enhancing effect of direct gaze on recall was not statistically significant when shown on a video, although the effect was observed in a corresponding experiment that used a live presentation. This result might be related to the lack of being seen by the instructor. Interestingly, significant, positive effects of direct gaze on recall have also been found using video-mediated presentations when the participants knew that they were seen by the person on the video through a video link (Fullwood & Doherty-Sneddon, 2006). In the present study, we decided to investigate not only the effect of self-directed eyes on performance, but also the effect of knowledge of being seen by those eyes. To this end, we used a similar half-silvered mirror deception procedure that was used in Myllyneva and Hietanen (2015) study.

Some studies indicate that the effect of gaze on arousal and on performance might be different between male and female participants. In one study, only female participants showed enhanced autonomic responses (i.e., pupil dilation responses) to direct gaze (Porter, Hood, Troscianko, & Macrae, 2006). In another study, gender differences in the effect of eye contact on performance were observed with children (Otteson & Otteson, 1980). In addition, several studies that have investigated nonverbal communication in social interaction have found gender differences in gazing patterns (Argyle & Dean, 1965; Kendon & Cook, 1969; Kleinke, 1986; Mulac, Studley, Wiemann, & Bradac, 1987). Gender differences in gaze behavior have been observed to occur also in context of collaborative problem solving (Whitelock & Scanlon, 1998). Nevertheless, in most studies on direct gaze and arousal, or on direct gaze and performance, possible gender differences have not been investigated. In the present study, we wanted to investigate the possible effect of gender by having both male and female storytellers and participants that were paired in same-sex and mixed-sex pairs.

To summarize, in the present study, we investigated participants’ memory performance in recalling a story while we manipulated the level of direct gaze in a factorial manner (that is, direct gaze versus downcast gaze) and the awareness of being seen or not by the storyteller. As we assumed that the effect of direct gaze on memory might be different in different phases of the memory process, we wanted to restrict the exposure of direct gaze to the “intake”- phase. As both positive and negative effects of direct gaze have been reported, we expected that both positive and negative effects of direct gaze on performance could be observed in this study too. Importantly, however, we expected that this effect would be mediated by autonomic, affective arousal. To investigate this hypothesis, we measured variability in participant’s skin conductance while they were listening the stories. We hypothesized that direct gaze would enhance autonomic arousal which, in turn, would be associated with the memory performance. In addition, we hypothesized that the effect of direct gaze on arousal and memory performance would be stronger when the participants knew that they were seen by the storyteller, compared with not being seen.

**Materials and methods**

**Participants**

24 males (mean age = 27.1, range = 19–53 years) and 22 females (mean age = 25.5
years, range = 19–39 years) participated in the study. All participants were right handed and had normal or corrected-to-normal vision. They all were native speakers of Finnish, in which language the stories of this experiment were told. All the data from four male participants and one female were discarded because of technical difficulties in the experimental procedure or because the participants (two males) kept their eyes closed while the stories were read. Additionally, the physiological data of two male participants and two female participants were rejected because of technical difficulties. Hence, 20 males and 21 females contributed to the story recall data, and 18 males and 19 females contributed to the skin conductance data. The participants were recruited from local universities and through advertisements in social media. The participants gained a movie ticket or course credits for participation.

Stimuli and experimental procedure

Four stories (110–114 words in each) written for the purpose of this study were read to the participants one by one. The reading of each story took about 1 min. The storyteller heard prerecorded stories from an earpiece, which helped him/her to repeat the story word by word in the same rhythm in every session. The stories were read by either a male or a female experimenter, who were assigned to male and female participants, thus creating both same-sex and opposite-sex pairs. Both storytellers were young adults, who were not familiar with the participants before the experiment. After each story, the participant was asked to repeat everything that she/he could recall from the story. The participant was informed that the experimental situation was filmed by a hidden video camera, for the purpose of recording his/her answers. The purpose of hiding the camera and emphasizing the need of recording the answers was to avoid raising the participant’s awareness of being videofilmed during the storytelling. The camera was positioned at about 45° to the left from the participant’s frontal midline. In addition to recording the answers, the videos were used to ensure that the participants were looking at the stimulus person during the storytelling phase. Another camera was filming the storyteller from behind the participant.

The storyteller read the stories behind a computer-controlled liquid crystal (LC) window that was placed between the participant and the storyteller, 70 cm from the participant’s face and 50 cm from the storyteller’s face. The voltage sensitive LC window was made transparent during the storytelling and opaque during the retention phases of the experiment, thus the storyteller’s face was visible to the participant only during the storytelling phase. In addition, a half-silvered mirror type of a sheet attached to the LC window was presented to the participants. The participants were led to believe that when this sheet was slid on the window, the storyteller could not see the participant even though the participant could see the storyteller. In reality, the “half-silvered mirror” was a piece of transparent plexiglass sheet. Whether this “half-silvered mirror” was used or not, it created two different conditions: a belief of being seen (BS) –condition where the participant believed that she/he was seen by the storyteller, and a belief of not being seen (BnS) –condition where the participant believed that she/he was not seen by the storyteller, even though she/he saw the storyteller. A similar procedure was carried out as in a study by Myllyneva and Hietanen (2015) to realize the deceit.

Two stories were read to the participant in each state of belief condition. One story was read with a direct gaze and another one with downcast gaze. In the direct gaze condition, the storyteller was instructed to
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keep direct gaze as much as she/he felt natural during the storytelling, although she/he was allowed to take short downcast gaze shifts from time to time. The position of the participant and height of the storyteller’s chair were carefully adjusted before storytelling, so that the storyteller’s and participant’s eyes met at the same level in the middle of the window. Also, the participant was instructed to stay still during the storytelling to ensure good quality of physiological recordings. By means of this procedure, in both states of belief conditions, the storyteller’s direct gaze was directed towards participant’s eyes, thus enabling eye contact. In the downcast condition, the storyteller maintained a downcast gaze all the time during the storytelling. Thus, the study contained four conditions in a 2 x 2 design. The four stories were randomly assigned to these experimental conditions.

The amount of the storyteller’s direct gaze and the number of gaze shifts were analyzed afterwards frame by frame from the videos showing the storyteller’s face. In the direct gaze condition, the storytellers held the direct gaze on average 60.72 % (SD = 0.14) of time, and turned his/her gaze down 14.50 (SD = 0.51) times during a story. In the downcast gaze condition, both storytellers kept their eyes down for whole time with only one exception. During one male participant’s session, in the BS condition, the male storyteller accidentally took a short glance directed to participant’s face, lasting for 1 s. To investigate whether the experimental condition (BS vs. BnS), storyteller’s gender, and participant’s gender had an effect on the amount of storytellers’ direct gaze and on the number of gaze shifts, 2 x 2 x 2 split-plot ANOVAs and appropriate t-tests were performed. The amount of direct gaze did not differ between the female (M = 59.85 %, SD = 1.72) and male (M = 61.54 %, SD = 2.12) storytellers (t(38) = 0.74, ns.), but the female storyteller made significantly more gaze shifts (M = 15.97, SD = 0.68) than the male (M = 13.10, SD = 0.62) storyteller (t(38) = -3.23, p = 0.003). Surprisingly, the state of belief condition affected the storytellers’ gaze behavior, even though they could see the participant through the window similarly in both conditions. The storytellers held the direct gaze slightly but significantly less (M = 58.96 %, SD = 1.70 vs. M = 62.48 %, SD = 1.27, t(38) = -2.78, p = 0.008) and they made more gaze shifts (M = 15.36, SD = 0.60 vs. M = 13.64, SD = 0.50, t(38) = 3.91, p < 0.001) in the BS condition compared with the BnS condition. The storyteller’s or participant’s gender did not interact with state of belief condition.

After the experiment, the storyteller interviewed the participant about his/her thoughts and feelings during the experiment. Any doubts about the deception were registered. After this, the deception was revealed, and the participants were asked directly if she/he had doubted the half-silvered mirror manipulation. One female and two male participants commented that they had some doubts about the deception, but only after the deception was revealed to them. Thus, they were included in the analysis. In the end of the experimental session, the participants were asked to fulfill a questionnaire assessing the fear and avoidance of eye contact (Gaze Anxiety Rating Scale, GARS, Schneier, Rodebaugh, Blanco, Lewin, & Liebowitz, 2011). Male and female participants did not differ in their gaze anxiety scores (total M = 22.32, SD = 8.16 vs. M = 21.10, SD = 8.10, respectively, t(39) = 0.49, ns.).

Psychophysiological measurements

For skin conductance measurements, the electrodes (Ag/AgCl, diameter 5 mm) were coated with isotonic electrode paste and attached to the palmar surface of the distal phalanxes of the index and middle fingers on the participant’s left hand. The electrodes were attached in the very beginning of the procedure, thus ensuring
that they were attached at least five minutes prior to the recordings. The data were collected with DC methodology (1/25000 A), with 500 Hz sampling rate, using QuickAmp amplifier and Brain Vision Professional Recorder running on a PC computer. The change between the transparent and opaque state of the LC window was controlled by E-Prime 2.0 program which also sent simultaneous trigger signals to the physiological data collection equipment.

Data analysis

Memory performance

Memory performance was scored from videos by a rater who was blind to the gaze direction and the state of belief condition during the storytelling. The contents of each story were divided into 50 semantic details, and the rater evaluated whether or not the participant recalled each of these details. The participant scored 1 point for every detail; thus, the maximum score for memory performance was 50 points. Furthermore, to control for differences in the difficulty of the four stories, the scores for each story were standardized (z-scores) over all the participants whose data were included into the analyses.

Skin conductance

The studies investigating the effect of direct gaze on skin conductance measures of arousal have most often quantified the response as an amplitude or magnitude of phasic skin conductance responses following the onset of the stimulus (e.g., Hietanen et al., 2008; Helminen et al., 2011; Myllyneva & Hietanen, 2015; Conty et al., 2010; see also Boucsein, 2012, for description of the methodology). This approach was not applicable in the present study, as the stimulus was a one-minute-long storytelling period that included seeing the storyteller and memorizing the contents of the spoken story. Therefore, we adapted a methodology introduced by Figner and Murphy (2011), and calculated the area bounded between the filtered skin conductance curve and the abscissa. This method combines the frequency and shape parameters (for instance, amplitude and recovery time) of the phasic skin conductance responses, and reflects the variability of skin conductance. Frequency of nonspecific skin conductance responses and shape parameters are known to reflect different aspects of arousal, and recovery time of single skin conductance response, for example, has been associated with attention and memory storage (Boucsein, 2012). The skin conductance data were first analyzed with Brainvision Analyzer 2.0. The skin conductance signal during the whole recording session from each participant was filtered from 0.5 to 2.0 Hz (24 dB/oct slope) with Butterworth Zero Phase filters. After this, the data were segmented to four segments containing the four storytelling phases of the experiment. The absolute integral for each segment was calculated using LabChart Pro v.7.3.7 program. As the lengths of the segments varied slightly due to the small differences in the lengths of the stories, the integral was divided by the length of the segment in seconds and multiplied by 60, resulting in

1 The means (SDs) and ranges of the raw scores for each story were as follows: A: 23.2 (7.2), 8–37; B: 21.9 (5.9), 11–39; C: 25.9 (7.5), 7–39; D: 24.0 (6.2), 10–36. The story C was significantly easier than the story A ($t(40) = -2.52, p = 0.016$) and the story B ($t(40) = -3.73, p = 0.001$). Story B was also significantly more difficult than story D ($t(40) = -2.18, p = 0.035$).
the final measurement units of µS/min. Finally, the skin conductance measures were ln-transformed (ln(x + 1)).

**Statistical analyses**

The memory performance and skin conductance data were analyzed separately with ANOVAs where the gaze direction (direct, downcast) and state of belief condition (BS, BnS) were specified as within-subject variables and storyteller’s gender and participant’s gender as between-subject variables. Multiple comparisons are reported without corrections following Rothman (1990). All the statistical analyses for skin conductance variability were performed on ln-transformed data, but the parameter means in the text and in the figures are reported as untransformed values. The analyses of variance and planned comparisons were performed with SPSS statistics 21.

A path analysis was performed to investigate whether sympathetic arousal, indexed as variability in skin conductance, mediated the association between the gaze direction and memory performance. In addition to testing mediation, path models enable simultaneous assessment of multiple processes (see e.g., Preacher, Rucker, & Hayes, 2007). Thus, we wanted to investigate whether the participants’ and storytellers’ gender moderated the effect of gaze on learning. For the path model, some additional variable transformations were performed. To control for individual differences in the memory performance, the individual mean of the memory performances across the four stories was subtracted from the participant’s scores in each story. Similarly, each participant’s mean ln-transformed skin conductance value was subtracted from the skin conductance values in the four study conditions. The results of the above-mentioned ANOVAs were used to specify the path models, which were then estimated in Mplus version 7.11, with maximum likelihood (ML) estimator and bootstrapped standard errors (10,000 draws). The differences in the path estimates between males and females were evaluated by the ratio of the difference to the standard error of the difference. The significance of this ratio, reflecting difference in the two paths, is determined by the standard normal distribution (Bollen, 1989).

Normality of distribution was investigated with Shapiro–Wilk’s tests separately for all experimental conditions and for both genders. The ln-transformed skin conductance values were normally distributed in direct and averted gaze conditions when averaged over BS and BnS conditions, but positively skewed for females in the BS direct, BS downcast, and BnS downcast conditions, and for males in the BS downcast and BnS direct conditions. According to Norman (2010), parametric tests such as ANOVA can be used for non-normal distributions. Hence, the ANOVAs were carried out despite the skewness of the distribution. In addition, the bootstrap method used in the path analysis does not require normality of the distributions (Preacher et al., 2007).

**Results**

**Memory performance**

A 2 x 2 x 2 x 2 split-plot ANOVA was performed on the standardized memory performance scores, Gaze (direct, downcast) and State of Belief condition (BS, BnS) as within-subject variables, and Participant’s gender and Storyteller’s gender as between-subject variables. A three-way interaction was found between Gaze, Storyteller’s gender, and Participant’s gender, $F(1,37) = 9.38, p = 0.004, \eta^2_p = 0.202$. None of the other interactions or main effects were statistically significant.

The standardized memory performance scores were averaged over the BS and BnS conditions separately for direct and averted
gaze conditions. A Gaze x Storyteller’s gender ANOVA was run separately for the male and female participants. For the males, the analysis showed an interaction between Gaze and Storyteller’s gender, $F(1,18) = 13.55, p = 0.002, \eta^2 = 0.430$ (see Fig. 1). Pairwise comparisons showed that the effect of Gaze was statistically significant when the storyteller was a female ($n = 10$), $t(9) = -3.84, p = 0.004$. Male participants remembered the story better when the female storyteller’s gaze was downcast ($M = 0.21, SD = 1.05$) compared to a direct gaze ($M = -0.23, SD = 0.93$). For the male storyteller, ($n = 10$), the effect of gaze approached significance, $t(9) = 2.04, p = 0.07$. The male participants performed better when the direction of the male storyteller’s gaze was direct ($M = 0.34, SD = 0.83$) as compared to downcast gaze ($M = -0.08, SD = 0.89$). For the female participants, a similar two-way ANOVA as above did not reveal any significant main or interaction effects (see Fig. 1).

Fig. 1 Means and standard errors of the standardized memory performance scores for male and female participants in different gaze conditions.

Fig. 2 Mean variability and standard error of skin conductance variability (untransformed) during storytelling in the two gaze conditions separately for the male and female participants. Error bars standard errors.
Affective arousal

A similar four-way split-plot ANOVA as above was performed on the skin conductance data. The analysis showed an interaction between Gaze and Participant’s Gender $F(1,33) = 5.20, p = 0.029, \eta^2 = 0.136$. The main effect of Participant’s Gender was also significant, $F(1,33) = 8.13, p = 0.007, \eta^2 = 0.198$. Male participants had more variability in skin conductance ($M = 0.42, SD = 0.23$) than females ($M = 0.23, SD = 0.22$). The main effect of Gaze was approaching significance, $F(1,33) = 3.82, p = 0.059, \eta^2 = 0.104$, indicating that, overall, participants were more aroused in the direct gaze condition ($M = 0.36, SD = 0.31$) than in the downcast gaze condition ($M = 0.29, SD = 0.21$). There were no other significant main or interaction effects. As the state of belief condition had no effects on the results, the data were averaged over the BS and BnS conditions separately for the direct and downcast gaze conditions. The results were analyzed also independent of whether the participant saw the male or the female model. Pairwise comparisons showed that the male participants had more variability in skin conductance in the direct gaze condition ($M = 0.50, SD = 0.34$) than in the downcast condition ($M = 0.35, SD = 0.16$), $t(17) = 2.33, p = 0.033$. For the female participants, there was no effect of gaze, $t(18) = -0.47, p = 0.643$. Comparison between the genders showed that the direct gaze was significantly more arousing for the males than females ($M = 0.22, SD = 0.20$), $t(35) = 3.16, p = 0.003$. In the downcast gaze condition, the difference between genders was approaching significance, $t(35) = 1.994, p = 0.054$, males having again more variability in skin conductance than females ($M = 0.24, SD = 0.25$) (see Fig. 2).

Does arousal mediate the effect of gaze on learning?

As the analyses of variance showed that gaze affected differently the males’ and females’ memory performance as well as their skin conductance variability, the path models were specified separately for the males and females by the multiple group method. Also, the moderating effect of the storyteller’s gender on the relationship between gaze and memory performance was investigated. As the state of belief condition did not have an effect on the results, it was not included into the analysis. Downcast gaze direction and the female storyteller were used as the reference conditions, to which the effects of direct gaze and male storyteller were compared. Path models are illustrated separately for the female and male participants in Fig. 3. For the male participants, if a female storyteller had a direct gaze, variability in skin conductance increased ($a = 0.09, 95\% CI [0.03, 0.15], p = 0.007$). Variability in skin conductance, in turn, had a negative effect on the memory performance ($b = -1.42, [-2.43, -0.41], p = 0.006$). The direct path between the gaze direction and memory performance was not significant ($c^2 = -0.30, [-0.65, -0.06], ns.$). However, the storyteller’s gender moderated the path between the gaze direction and memory performance. If the storyteller was a male instead of a female, his direct gaze had a positive, direct effect on memory performance ($c^1 = 0.81, [0.32, 1.31], p = 0.001$). Instead, when compared to the female storyteller’s downcast gaze, the male’s downcast gaze had a negative effect on the performance ($c^2 = -0.41, [-0.77, -0.041], p = 0.029$).

In the female participants’ model, in accordance with the analysis of variance presented above, direct gaze did not affect skin conductance variability ($a = -0.02, [-0.08, 0.05], ns.$) or memory performance.
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Fig. 3 Conceptual diagrams of the path models for the male (a) and female (b) participants, showing regression coefficients, bootstrapped standard errors in brackets, and significances with asterisks. A female storyteller and averted gaze were used as references in the models.

For male participants:
- \( a = 0.09 \) (0.03)**
- \( b = -1.42 \) (0.52)**
- \( c' = -0.30 \) (0.18)
- \( c'' = -0.41 \) (0.19)*
- \( c''' = 0.81 \) (0.25)***

For female participants:
- \( a = -0.02 \) (0.03)
- \( b = -1.87 \) (0.58)***
- \( c' = 0.06 \) (0.17)
- \( c'' = 0.15 \) (0.14)
- \( c''' = -0.30 \) (0.22)

For male storyteller:
- \( c'' = -0.41 \) (0.19)*

For female storyteller:
- \( c' = -0.28 \) (0.40), ns.

Storyteller’s gender did not moderate the connection between direct gaze and memory performance \( (c'' = -0.30, \ [-0.74, 0.13], \text{ns.}, \text{for male storyteller}).\) Furthermore, in the downcast gaze condition, storyteller’s gender had no effect on memory performance \((c'' = 0.15, \ [-0.13, 0.43], \text{ns.}).\) Comparison of the paths in the females’ model to the corresponding paths in the males’ model showed that there were significant differences in the paths between the direct gaze and arousal \( (A_{\text{diff}} = 0.10, \ [0.02, 0.19], \ p = 0.020), \) in the modulatory effect of the storyteller’s gender \( (C_{\text{diff}} = 1.11, \ [0.46, 1.77], \ p = 0.001), \) and in the main effect of the storyteller’s gender \( (C_{\text{diff}} = -0.56, \ [-1.01, -0.10], \ p = 0.017).\) In the females’ model, like in the males’ model, a significant negative path existed between the arousal and memory performance \( (b = -1.87, \ [-3.01, -0.72], \ p = 0.001), \) and this negative path between arousal and memory performance was equal in both groups \( (B_{\text{diff}} = 0.45, \ [-1.07, 1.97], \text{ns.}).\)
The path models of both groups had an excellent fit ($\chi^2_{\text{men}} = 0.28$, df = 2, $p = 0.869$; $\chi^2_{\text{women}} = 0.64$, df = 2, $p = 0.726$; Kline, 2011). Both models explained about a fifth of the variance in the memory performance ($R^2_{\text{males}} = 20\%$, $R^2_{\text{females}} = 22\%$).

Discussion

The purpose of this study was to investigate the effect of a storyteller’s gaze direction on memory performance in a live interaction situation, and to investigate the possible role of physiological arousal in mediating this effect. The results of the study showed that, with male participants, the storyteller’s gaze direction had an effect both on arousal and on memory performance. Unexpectedly, no effects of gaze direction were found among female participants neither on performance nor arousal. Here, we will first discuss the results found among male participants, and then the lack of finding the effect of gaze among females. In the present study, we also manipulated the participants’ belief of being seen by the storyteller. Contrary to our expectations, we did not find any effects of this manipulation on arousal or on memory performance. This will be discussed in the end.

In line with our hypotheses, the male participants were more aroused when the storyteller had a direct gaze compared to having a downcast gaze. According to our path analysis, arousal mediated the effect of direct gaze on performance negatively. However, parallel to this arousal-mediated process, there was another process between gaze and performance affecting performance positively. The effect of this process was observed only when the storyteller was a male. The positive effect of this process was stronger that the negative effect of arousal, hence, as an outcome, the effect of direct gaze on performance was positive. The arousal-mediated negative outcome of direct gaze on performance was observed only when the storyteller was a female.

Why was the effect of arousal on performance negative then? It is very likely, that the reason for this is related to the close relationship between arousal and attentional processes (see e.g., Eysenck, 1982; Coull, 1998). Elevated arousal narrows attention to fewer stimulus elements in the environment, reduces ability to discriminate between relevant and irrelevant stimuli, and increases attentional lability (Eysenck, 1982). In addition, as a strong internal signal, enhanced arousal might trigger self-focused attention (Silvia & Gendolla, 2001; Wegner & Giuliano, 1980). Processing self-related information would require cognitive resources which, in turn, would reduce resources available to a current task. Alternatively, it is possible that the enhanced arousal might promote processing of the stimulus triggering the elevated arousal, in this case, the person who is looking at you. This suggestion is in line with results showing that features of faces presented with direct gaze are processed more efficiently than features of faces presented with averted gaze (Hood et al., 2003; Macrae et al., 2002). Furthermore, an incidental presentation of direct gaze has been shown to interfere cognitive performance in a task not related to eyes (Conty, Gimmig, Belletier, George & Huguet, 2010). Like with self-focused attention, focusing attention on a counterpart could also reduce resources available to listening and memorizing the stories.

However, as shown by our path analysis, the effect of gaze was not only mediated by arousal, but the direct gaze influenced performance also through some other process which had a positive effect on performance. Interestingly, in his review on the mediating role of arousal between the presence of another person and performance, Kushnir (1981) suggested that there exists at least two operationally distinct mechanisms
underlying the effect of another person’s presence on performance: one being related to unintentionally induced arousal, and another related to effort and voluntary attention allocation to the task. Moreover, several researchers have proposed that instead of a single dimension of general arousal, there exist two or more arousal systems functioning at least partly independently from each other (see reviews by Bouscein, 2012; Eysenck, 1982). In these multidimensional arousal theories, “effort system” is considered as one of the arousal systems, separate from the affective arousal system. As these separate systems seem to have also different neurophysiological underpinnings, the activation of these systems is presumably reflected differently in different psychophysiological measures (Boucsein, 2012). Our measure reflected phasic changes in skin conductance, a commonly used index of affective arousal considered to be regulated by subcortical structures, especially the amygdala (see e.g., Boucsein, 2012; Laine et al., 2009; Lang & Bradley, 2010). Instead, other measures such as heart rate variability (e.g., Börger et al., 1999; Segerstrom & Nes, 2007) or tonic changes in cortical arousal (Howells, Stein, & Russell, 2010) may reflect effort allocation. Thus, we suggest that the influence of direct gaze on performance is mediated by at least two different processes that can have reverse influence on outcome. According to the present results, the affective arousal mediated negatively the effect of direct gaze on performance, but parallel to this process, direct gaze affected performance positively, presumably by affecting effort allocation. However, this positive effect of direct gaze was seen only when male participants were facing a male storyteller.

The amount of effort allocated to the task is influenced by motivational factors (Eysenck, 1982). Intuitively, a self-directed gaze can be considered as a motivational stimulus, giving weight to what is being said, thus, influencing effort allocation. In light of our results, one needs to ask, however, why would this effect be moderated by a counterpart’s gender? We suggest that differences in interpretation of the social meaning of direct gaze might explain the observed differences between the male participants facing male versus female storytellers. For example, socio-cultural norms have an influence on how a male’s vs. female’s direct gaze is interpreted (Burgoon, Guerrero, & Floyd, 2010; Henley, 1995). A female’s direct gaze might be interpreted as a sexual cue (Abbey & Melby, 1986), which might lead males to put effort on self-monitoring to make a good impression, instead of putting more effort on task performance. Similar explanations have been suggested in studies showing that interacting with a woman, and even merely anticipating an interaction with a woman, has a negative influence on male participants’ performance (Karremans, Verwijmeren, Pronk, & Reisma, 2009; Nauts, Metzmacher, Verwijmeren, Rommeswinkel, & Karremans, 2012). When the counterpart is another man (and the situation does not contain factors that would promote, e.g., competition), there is no apparent need for self-monitoring to make a good impression, but rather, the direct gaze might be interpreted, e.g., as a sign of encouragement or confidence. This, in turn, would motivate to put more effort on the task. Thus, we suggest that the influence of a direct gaze on effort allocation depends on the interpretations about the meaning of the gaze. This is, of course, only a hypothetical suggestion, and more empirical evidence is needed to test whether this is the case.

An alternative explanation for the positive effect of a male storyteller’s direct gaze on learning arises from the motor resonance and common coding theories (e.g., Hommel, Müßeler, Aschersleben, & Prinz, 2001). According to these theories, perceptual and motor systems share a common coding system, and the motor
system is activated in perception. Speech perception has also been explained using this framework (the motor theory of speech perception, see e.g., Galantucci, Fowler, & Turvey, 2006) and suggested to activate the motor speech systems. It is possible that motor resonance had a positive impact on learning the stories in the present study. In the context of motion perception, males have been found to show stronger motor resonance when observing males’ than females’ movements (Anelli, Borghi, & Nicoletti, 2012). In the present study, a male’s storytelling might have triggered stronger motor resonance in males compared to a female’s storytelling, thus resulting in a better story recall. However, our male participants did not show superior performance for a male’s storytelling overall, but only when the gaze was direct. There is some evidence that motor resonance to facial expressions as measured by facial electromyography is stronger in the context of direct vs. averted gaze (Schrammel, Pannasch, Graupner, Mojzisch, & Velichkovsky, 2009; Soussignan et al., 2013) although this is not a consistent finding (see Mojzisch et al., 2006). In addition, in a brain imaging study, no effect of head and gaze direction was observed on the mirror neuron system activation (Schulte-Rüther, Markowitsch, Fink, & Piefke, 2007). Taken together, the motor resonance theory may be able to explain the pattern of results of the present study although cautiousness is warranted as this suggestion is highly speculative at the moment.

Presumably, both affective arousal and effort allocation have an effect on attentional processes, as already mentioned. In future studies, it would be valuable to measure participants’ gaze behavior with eye tracking devices to evaluate their attention allocation. Previous studies have shown that averting one’s gaze from an instructor’s face can be associated with better performance in cognitively demanding tasks (Glenberg, Schroeder, & Robertson, 1998; Markson & Paterson, 2009). Thus, it would have been very interesting to see whether, in our sample, the male participants were fixating more on female storyteller’s eyes compared to male storyteller’s eyes. Unfortunately, even though we had a camera filming the participants, the quality of the video data was not good enough for measuring how much the participants looked at the storytellers’ face region.

Surprisingly, among female participants, we did not find the effect of gaze direction neither on memory performance nor on arousal. As far as we know, the only previous study showing that females might not respond to direct gaze as strongly as males while performing a memory task was the study by Otteson and Otteson (1980) with primary school children. In previous studies investigating the effect of direct gaze on arousal, both females and males have been found to respond to direct gaze with enhanced arousal responses (Nichols & Champness, 1971; Helminen et al., 2011; Hietanen et al., 2008; Myllyneva & Hietanen, 2015; Pönkänen et al., 2011). Thus, we are cautious in drawing any conclusions about this result. However, the result might suggest that females, compared to males, are less vulnerable to incidental social cues during cognitive tasks. Previous research has shown that females tend to take more eye contact than males (Bente, Donaghy, & Suwelack, 1998; Mulac, Studley, Wiemann, & Bradac, 1987; Whitelock & Scanlon, 1998); hence, it is possible that a direct eye gaze was a less conspicuous social signal for female than male participants. The present result can also be interpreted in the frame of multitasking, that is, the participants were required to concentrate on a cognitive task at the same time while being in nonverbal interaction with another person. There exists some empirical evidence showing that females show better inhibition of distracters and better cognitive control than males in multitasking conditions (Ren, Zhou, & Fu, 2009). Thus, perhaps, the females could
concentrate better on the task at hand and inhibit the effects of a storyteller’s gaze. It is also good to note the present results showing that female participants had overall less variability in skin conductance compared to males, which are in line with Boucsein’s (2012) notion that males tend to show greater electrodermal reactivity than females to sensory stimulation. Hence, it is possible that females’ autonomic nervous system reactions in different gaze conditions were too subtle to be captured with our measure. Altogether, more research is needed to see how consistent the results concerning the gender differences are.

In the present study, we also investigated if the awareness of being seen by the storyteller modulates the effect of eye contact on memory performance and on arousal. We manipulated the participants’ belief of whether they were seen or not by the storyteller with the same kind of a manipulation as Myllyneva and Hietanen (2015). In that study, differential skin conductance responses to direct versus averted gaze were found only when participants knew that they were seen by the model person. Thus, their result suggested a strong top-down modulation by mentalization on autonomic nervous system responses to direct gaze. However, contradictory to their results and against our hypothesis, in the present study, the manipulation of the belief of being seen did not have an effect on either story recall or on arousal. There are several possible explanations for this discrepancy arising from methodological differences between that and the present study. First, in Myllyneva and Hietanen’s (2015) study, participants were passively watching the stimuli, whereas in the present study, the participants performed a cognitively demanding task. According to Conty et al. (2010), enhanced arousal responses to direct gaze might be particularly well observed when the eyes are presented incidentally to a cognitively demanding task, presumably because there are no cognitive resources available for cortical modulation of subcortically induced responses. Thus, it is possible that, in the present study, the effects of the cognitive task suppressed the effects of mentalizing and, therefore, no differences between the two states of belief conditions were observed. Second, Myllyneva and Hietanen measured magnitudes of single phasic skin conductance responses following the onsets of the face stimuli and reflecting the orientation reaction, while we used an area measure of the electrodermal fluctuations during continuous stimulus presentation and cognitive task. Third, in our study (and not in Myllyneva and Hietanen), participants were informed in the beginning of the experiment that they were being filmed by a hidden camera for the purpose of evaluating their answers in the free recall task. Awareness of being filmed during the whole experimental session might have raised participants’ awareness of being observed (see for example Govern & Marsch, 2001) and, therefore, minimize the differences between BS and BnS conditions.

The analysis of the storytellers’ eye gaze behavior revealed that, surprisingly, the storytellers were influenced by the state of belief manipulation. We decided not to control the timing of the storytellers’ gaze turns precisely as we wanted to keep the situation as natural as possible. As a result (as revealed by the off-line video analysis), the storytellers took slightly but significantly more direct gaze in the condition where they knew that the participants thought that they were not seen by him/her. This result implies that our storytellers accommodated their gaze behaviour according to what they thought that the participants thought they were not seen by him/her. This result implies that our storytellers accommodated their gaze behaviour according to what they thought that the participants were thinking. The finding is interesting as such, but also raises considerations. It is possible that the observed differences in the amount of direct gaze between the BS and BnS conditions might explain the lack of the effects of the state of belief manipulation on our participants’ performance and arousal.
Perhaps, larger amount of direct gaze in the BnS condition compensated the intended differences between the state of belief conditions. It was expected that the effect of gaze direction on performance and arousal would be less pronounced when the participants thought that they were not seen by the storyteller. However, larger amount of eye contact might have led to higher intimacy and to higher arousal, as suggested, for example, by Patterson’s (1976) arousal model of interpersonal intimacy. Even so, as far as we know, there is no empirical evidence that the increasing amount of eye contact would linearly enhance arousal. On the contrary, in Helminen et al. (2011) study, there were no differences in the magnitude of phasic skin conductance responses as a function of eye contact duration (2 vs. 5 s). Apparently, however, in future studies, it is important to control more precisely the amount of eye contact.

One limitation of this study was that only one female and one male were acting as storytellers. It has been shown that a female counterpart’s attractiveness influences how much her presence contributes to men’s cognitive performance (Karremans et al., 2009). This might have accounted for the arousing effect of the eye contact in this study too. In addition, perhaps, personality characteristics such as perceived dominance might have affected how much influence the storyteller’s gaze had on participants’ cognitive performance.

Taken together, the present study gave support to previous results indicating that eye contact has an effect on cognitive performance, and that this effect is mediated partly through affective autonomic arousal. Gender differences that were revealed in this study stress the importance of counterbalancing both the participants’ and the stimulus persons’ genders in future studies. Furthermore, it would be interesting to investigate further what kind of a role self-awareness raised by the belief of being seen plays in the relationship between eye contact and arousal. Despite that the belief of being seen did not show any effects on our results, we are not convinced that this belief would not modulate the effect of eye contact on performance and arousal. Investigating this issue further would be valuable, for example, when assessing the impact of direct gaze in video-based educational material. As already mentioned in the beginning of this article, the idea that the association between the experience of being seen and cognitive performance could be mediated via arousal is not new. As far as we know, this study is the first one to offer empirical evidence for this hypothesis. Moreover, by showing that the direct gaze can affect performance through multiple parallel processes and that these processes are moderated by variables such as gender of the interacting counterparts, the results reflect the complexity of socio-cognitive phenomena.

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Conflict of interest

The authors have no conflicts of interest.

Ethical standards

Informed, written consent was obtained from each participant in the beginning of the experimental procedure. The ethical statement for the study was obtained from the Tampere Area Ethical Review Board, and the study has therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments.

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Atypical Physiological Orienting to Direct Gaze in Low-Functioning Children with Autism Spectrum Disorder

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Reduced use of eye contact is a prominent feature in individuals with autism spectrum disorder (ASD). It has been proposed that direct gaze does not capture the attention of individuals with ASD. Experimental evidence is, however, mainly restricted to relatively high-functioning school-aged children or adults with ASD. This study investigated whether 2–5-year-old low-functioning children with severe ASD differ from control children in orienting to gaze stimuli, as measured with the heart rate deceleration response. Responses were measured to computerized presentations of dynamic shifts of gaze direction either toward (direct) or away (averted) from the observing child. The results showed a significant group by gaze direction interaction effect on heart rate responses (permuted $P = .004$), reflecting a stronger orienting response to direct versus averted gaze in typically developing ($N = 17$) and developmentally delayed ($N = 16$) children but not in children with ASD ($N = 12$). The lack of enhanced orienting response to direct gaze in the ASD group was not caused by a lack of looking at the eye region, as confirmed by eye tracking. The results suggest that direct gaze is not a socially salient, attention-grabbing signal for low-functioning children with ASD. Autism Res 2017; 10: 810–820. © 2016 International Society for Autism Research, Wiley Periodicals, Inc.

**Keywords:** autism spectrum disorder; eye contact; attention; orienting; heart rate

**Introduction**

The bias to look at others’ faces is an early emerging and pervasive characteristic of normative human behavior [Goren, Sarty, & Wu, 1975; Mondloch et al., 1999; Valenza, Simion, Cassia, & Umiltà, 1996]. Human neonates prefer faces with open eyes over closed-eyes faces [Batki, Baron-Cohen, Wheelwright, Connellan, & Ahluwalia, 2000] and orient more often and look longer at faces with direct gaze than with averted gaze [Farroni, Csibra, Simion, & Johnson, 2002]. A similar bias for faces with direct gaze was found in older children and adults, as demonstrated by faster localization of faces with direct gaze than with averted gaze [Böckler, van der Wel, & Welsh, 2014; Conty, Tijus, Hugueville, Coelho, & George, 2006; Doi, Ueda, & Shinohara, 2009; Senju, Hasegawa, & Tojo, 2005a; Von Grünau & Anston, 1995], and by longer visual attention on faces with direct than averted or closed eyes [Palanica & Itier, 2012; Senju & Hasegawa, 2005]. The capability of direct gaze to attract and hold attention stresses the important role of mutual gaze in social interaction.

While the attentional bias for faces with direct gaze is strong in healthy children and adults, it may be absent or altered in individuals with autism. Abnormal use of eye contact is a prominent feature of autism spectrum disorder [ASD; American Psychiatric Association, 2013]. The abnormality most often manifests as reduced use of eye contact, which is already present around the child’s first birthday or even earlier [Maestro et al., 2005; Osterling & Dawson, 1994; Osterling, Dawson, & Munson, 2002; Zwaigenbaum et al., 2005]. A lack of differential neural responses to gaze shifts toward and away from the observer has been found during the first year of life in infants who were later diagnosed with ASD [Elsabbagh et al., 2012]. An eye tracking study investigating gaze behaviour in 2-year-old children with ASD indicated reduced looking at the eye region in videos showing an adult engaging the viewer in age-appropriate social routines [Jones, Carr, & Klin, 2008]. However, other eye tracking studies have shown that the reduced scanning of the eye region when looking at pictures or video clips of social scenes is not a consistent finding [e.g., see a review by Falck-Ytter & von Hofsten, 2011; Chawarska, Macari, & Shic, 2012; Chawarska & Shic, 2009; From the Faculty of Social Sciences/Psychology, 33014 University of Tampere, Finland (T.M.H., J.K.H., A.K.); School of Medicine, 33014 University of Tampere, Finland (J.M.L.); Department of Pediatric Neurology and Tampere Center for Child Health Research, School of Medicine, 33014 University of Tampere, and Tampere University Hospital, Tampere, Finland (K.E.); School of Management, 33014 University of Tampere, Finland (A.L.) Received June 27, 2016; accepted for publication December 03, 2016 Address for correspondence and reprint: Terhi M. Helminen, Faculty of Social Sciences/Psychology, 33014 University of Tampere, Finland. E-mail: terhi.helminen@staff.uta.fi Published online 28 February 2017 in Wiley Online Library (wileyonlinelibrary.com) DOI: 10.1002/aur.1738 © 2016 International Society for Autism Research, Wiley Periodicals, Inc.
The effect of stimulus faces’ gaze direction on scanning patterns has not been systematically investigated, expect in Louwerse et al. [2013] study reporting that both adolescents with ASD and typically developing adolescents looked longer at the eye region of facial pictures with direct gaze compared to averted gaze or closed eyes pictures.

The reasons behind the reduced use of eye contact in ASD are still a matter of discussion. One hypothesis was proposed that individuals with ASD passively omit direct gaze, as it fails to capture their attention [Senju & Hasegawa, 2005; Senju & Johnson, 2009; Senju et al., 2005a] and is not socially motivating [Dawson, Webb, & McPartland, 2005; Mundy, 1995; Senju & Johnson, 2009]. The hypothesis of passive omission of eye contact posits that direct gaze does not capture the attention of individuals with ASD better than other gaze directions. In contrast to typically developing individuals, individuals with ASD do not show the advantage of detecting direct gaze more efficiently than other gaze directions in a stimulus array consisting of multiple faces [Senju, Yaguchi, Tojo, & Hasegawa, 2003; Senju et al., 2005a], except when the detection relies on low-level visual features of the eyes instead of configural information of the whole face [Senju, Kikuchi, Hasegawa, Tojo, & Osanai, 2008; Senju et al., 2005a]. In accordance with these behavioral results, pronounced attention-related ERP responses (N2) to direct versus averted gaze in a detection task were found in typically developing school-aged children but not in children with ASD [Senju, Tojo, Yaguchi, & Hasegawa, 2005b].

To further examine the merits of the passive omission of direct gaze hypothesis and the underlying reasons for reduced eye contact in ASD, we broadened the perspective of attentional processes from stimulus detection to physiological aspects of orienting. It has been well established that detecting a stimulus is accompanied with a physiological orienting response that manifests, for example, in a rapid deceleration of heart rate within the first few seconds after stimulus onset [Bradley, 2009; Courage, Reynolds, & Richards, 2006; Graham & Clifton, 1966; Ohman, Hamm, & Hugdahl, 2000]. This heart rate deceleration, thought to enhance attentional engagement with the stimulus and cognitive processing of the stimulus information, is affected by stimulus significance (“signal value”), which might have been associated with the stimulus either through innate readiness or learning [Ohman et al., 2000]. It was shown that direct gaze of another “live” individual triggers a greater heart rate deceleration than averted gaze in typical adult populations [Akechi et al., 2013; Myllyneva & Hietanen, 2015]. This deceleration response was also measured in Louwerse et al.’s [2013] study, which presented static facial pictures with different gaze directions to high-functioning adolescents with ASD and typically developing controls. In that study, the enhanced heart rate deceleration to direct gaze was found neither in the ASD nor in the control group. As no enhanced heart rate deceleration was found in the typically developing adolescents, which is in contrast to the results by Akechi et al. [2013] and Myllyneva and Hietanen [2015], the result could be related to the use of pictorial stimuli with static gaze in Louwerse et al.’s [2013] study.

Moreover, Louwerse et al. [2013] investigated high-functioning adolescents with ASD, and therefore, the findings cannot be generalized to young low-functioning children whose exposure to eye contact during their lifespan might have been very limited. High-functioning children are a much better represented group than low-functioning children in autism research because of the challenges in guiding these children through the experimental procedures [cf. Kylliäinen, Jones, Gomot, Wardyn, & Falck-Ytter, 2014]. Investigation of young low-functioning children is, nevertheless, highly recommended [e.g., Itier & Batty, 2009] for better understanding the early developmental origins of reduced eye contact in ASD, as school-aged high-functioning children with longer time for development and greater cognitive capacity have had more opportunities to acquire compensatory strategies for their disabilities. In addition, the subgroups within the spectrum may have different neuro-cognitive characteristics and may differ in their psychophysiological responding to eye gaze [see e.g., Joseph, Ehrman, McNally, and Keehn, 2008; Kaartinen, Puura, Himanen, Nevalainen, and Hietanen, 2016; Kaartinen et al. 2012], thus research focusing on different subgroups is essential.

This study focused on young low-functioning children with severe ASD to examine whether they differ from typically developing (TD) and developmentally delayed (DD) children in their orienting response (i.e., heart rate deceleration response) to dynamic shifts of gaze to direct and averted directions. The DD group was included to investigate whether developmental delay could affect physiological responses to gaze shifts. In TD and DD children, we expected to find a similar pattern as previously reported in adults [Akechi et al., 2013; Myllyneva & Hietanen, 2015], that is, a stronger heart rate deceleration response to direct than to averted gaze. However, we expected to find no difference in heart rate deceleration between direct versus averted gaze in low-functioning children with ASD. This finding would indicate that children with ASD do not show an enhanced orienting response toward faces with a direct gaze, reflecting the lack of social salience of direct gaze and supporting the passive omission hypothesis. As our interest was to investigate the physiological aspects of orienting caused by social salience of direct gaze and not the perceptual detection of gaze shifts, the participants’ attention was...
purposefully directed to the eye region by the task properties, and more importantly, the gaze behaviour was measured with an eye tracker to ensure that the children were looking at the eye region.

**Methods**

**Participants**

Twenty newly diagnosed children with autism (ASD) were recruited from the Department of Pediatric Neurology, University Hospital of Tampere, Finland. The diagnosis was confirmed with the Autism Diagnostic Observation Schedule-2 [ADOS-2; Lord et al., 2012] and Autism Diagnostic Interview-revised [ADI-R; Rutter, Le Couteur, Lord, and Faggioli, 2005] by research-certified examiners. According to the ADOS-2 comparison score, the level of ASD-related symptoms of the children ranged from moderate to high (see Table I), and theADI-R summary confirmed robust autistic symptoms. All the ASD children had problems in the use of eye contact as recorded and observed in the ADI-R and ADOS-2 respectively. Twenty TD children matched in chronological age and 18 DD children without ASD served as controls. The DD children were recruited from the same hospital as children with ASD, from the departments of Pediatric Neurology and Intellectual Disability Services. None of the participating children had epilepsy, motor handicap, clinically significant congenital heart disease or known ASD-related chromosome abnormalities. The developmental age in the ASD and DD groups was confirmed with the Social Communication Questionnaire (SCQ) [Rutter, Bailey, & Lord, 2003] completed by the parents (Table I). This study was part of the Autism and Gaze research project, which had been evaluated by the Ethical Committee of the Pirkanmaa Hospital District (ETL R12098). All procedures performed were in accordance with the ethical standards.

Five children with ASD were not co-operative in the experimental situation (e.g., refused to wear the electrodes) and were thus excluded from the final sample. One child with ASD and two children with DD did not provide enough accepted trials due to excessive movements and difficulties in concentration during the task. The data from one child with ASD and three TD children were rejected due to technical difficulties. In addition, one child with ASD was rejected from the final analysis because of extreme values in heart rate change scores.1 Thus, the final sample consisted of 12 children with ASD, 17 TD, and 16 DD children. The severity of autistic behaviour of the rejected children with ASD (ADOS-2 comparison score: $M = 6.8, SD = 1.5$) did not differ from the accepted children with ASD (ADOS-2 comparison score: $M = 7.3, SD = 1.8, t(18) = 0.66, P = .518$). The chronological age between the final ASD and DD group did not differ, $t(27) = 0.81, P = .426$; nor did the developmental age between the ASD and DD group, $t(26) = 0.77, P = .448$ (Table I).

**Stimuli and Procedure**

A series of computerized tasks was conducted while heart rate, EEG, and eye movements were recorded. The

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1For this child, the average heart rate deceleration from baseline was $-15$ bpm in direct gaze condition, which is $>3$ SDs below average of all the participants. He was also an outlier in terms of difference between the direct and averted gaze conditions, the difference being $>3$ SDs above average of all the participants.
order of the tasks was counterbalanced, but the task of
this study was always preceded at least by one other
short task. Special care was taken in guiding the chil-
dren through the experimental procedure, so that the
children with special needs could handle the situation
[cf. Kylliäinen et al., 2014]. Picture cards were used to
instruct the children, and small candies were used as
rewards. The child was seated 60 cm from the computer
screen in an adjustable children’s seat or on the
parent’s lap (2 in TD and 1 in DD group). The experi-
menter stayed close behind the child and assisted if
needed. The small test room was dimly lighted. Anoth-
er experimenter monitored the child’s behavior behind
a wall via digital video camera, which was attached to
the upper part of the computer screen. The child’s eye
movements were tracked using the live viewer function
of Tobii Studio 3.2.1.

For the stimuli, three young females were photo-
graphed with three different head orientations (rotated
45° to the left and right and direct) and three different
gaze positions (direct toward the camera, downward,
averted 45°). These photos were manipulated by taking
one photo of each head position and adding the eyes of
all the other gaze conditions. This way, we created
three images for each head orientation where only the
gaze direction varied. When presented on the computer
screen, the size of the picture was 10 × 10 in degrees of
visual angle, and the eyes of the faces were positioned
in the middle of the screen. A trial was launched by the exper-
imenter when the child was attending to the screen, the
intertrial interval lasting approximately 3 sec at
minimum. Next, a series of three facial pictures was pre-
sented, creating an impression of a dynamic sequence.
The sequence of events is illustrated in Figure 1. First, a
head rotated 45° to the left or right and having its gaze
down appeared on the screen. After 2 sec, the gaze
shifted up, either toward the camera (direct gaze) or in
the same direction as the head orientation (averted
gaze), lasting for 3 sec. The heart rate orienting reaction
was measured relative to this gaze shift. During the last
part of the trial, the head turned toward the camera,
while the direction of the gaze stayed either direct or
averted, and the child’s task was to either to pull or
push the face toward or away by moving the joystick,
with the task alternating between consecutive blocks.
The last part of the trial was included for the purpose
of EEG recordings (not reported here) and for keeping
the child engaged with the task. The child was
instructed to look at the screen until seeing a picture of
the joystick and hearing the instruction, “now you.”
The instructions were also supported with picture cards
and gestures by the experimenter. At the beginning of
each block of trials, two rehearsal trials with a picture
of a teddy bear’s face were presented. The total number
of 24 trials was divided into four blocks of six trials. In
each block, there were three trials with direct and three
trials with averted gaze conditions, presented in ran-
don order. Each face identity (3) was presented once
with each gaze direction (2) in one block. The order of
blocks was counterbalanced across participants.

Figure 1. Sequence of events in a single trial in the direct and averted gaze conditions. The analysis period (−500 ms before to
2000 ms after gaze shift) is highlighted with a blue background.
Trials were presented until the child lost his/her interest to the stimuli or until the maximum of 24 trials was reached, resembling procedures that are typically used in studies with infants and young children [e.g., Courage et al., 2006]. The average number of presented trials was 22.1 (Min = 8, SD = 4.5) in the ASD group, 21.7 (Min = 14, SD = 3.1) in the TD group, and 21.8 (Min = 15, SD = 3.4) in the DD group.

Measurements and Analysis

Video analysis. Each child's behavior in the experimental situation was carefully analysed offline from the videos recorded during the task to ensure data quality [cf. Kylliäinen et al., 2014]. Only the trials during which the child was attending to the screen, not displaying any major movements, and not being clearly distracted or restless during the first 4 sec of the trial were accepted for further analysis. Distracters in the environment (e.g., if the experimenter or parent was instructing the child) were also reasons for rejecting trials.

Heart rate. Heart rate was recorded with the Net Station 4.5.1 software (Electrical Geodesics, Inc.) at 250 Hz sampling rate, using two pregelled self-adhesive electrodes positioned to the left and right sides of the chest and attached to the polygraphic input box of the Geodesic EEG System running on a Macintosh computer.

The electrocardiography (ECG) signal was analysed using an in-house ECG tool 3 user-interface [Peltola, Hietanen, Forssman, & Leppänen, 2013] and scripts written for Matlab software (Mathworks, Natick, MA). First, to measure interbeat intervals, the R-peaks were detected using an automatic algorithm and checked and corrected manually when needed. Based on the interbeat intervals, the estimation of the mean heart rate (beats per minute, bpm) was calculated within 500-ms periods: 500 ms before and for 2 sec after the gaze shift. The 500 ms before gaze shift were used as baseline, and the baseline heart rate was subtracted from that of the post gaze shift epochs to form a measure for the heart rate change.

On average, 0.9% (SD = 2.1) of the trials were rejected due to unclear signal. Thus, after the rejection of trials from video and signal analysis, the heart rate analysis was based on an average of 11.8 trials (SD = 5.5) for ASD, 16.2 (SD = 6.1) for TD, and 14.7 (SD = 5.0) for DD children. The differences were not statistically significant.

Gaze data acquisition and analysis. Eye movements were recorded using a corneal-reflection eye-tracking system (Tobii TX300, Tobii Technology) integrated into the 23-inch test monitor. Before testing, the eye-tracker was calibrated for each participant using a five-point calibration in the Tobii Studio 3.2.1 program. After successful calibration (or as many attempts to recalibrate as the child was willing to do), the tasks written on E-prime were started, and eye movement data were collected and stored using E-prime extensions for Tobii (Psychology Software Tools, Inc.). The gaze data were analysed with the Matlab-based Timestudio 3.04 program [Nyström, Falck-Ytter, & Gredebäck, 2016] and Microsoft Excel 2013. The data for x and y coordinates were filtered with a moving median filter over 37 samples (123 ms) to remove technical artefacts and interpolated for a maximum of 60 samples (200 ms). The calibration was checked individually for each child and corrected offline when needed based on the location of the attention grabber.

To evaluate whether gaze behavior might have affected the heart rate, the gaze behavior was analysed only for children and trials that were included in the heart rate analysis. To ensure good data quality, a trial was only accepted for analysis if there were more than 50% data during the analysis period. In total, eye tracking data were analysed from 12 ASD, 14 TD, and 14 DD children.

Two areas of interest (AOI) were defined: the eyes AOI defined as a rectangular area of 220 × 90 pixels around the eyes (see Fig. 2) and whole-screen AOI covering the entire screen (1024 × 768 pixels). First, the looking time during the first 2 sec after the gaze shift was calculated for the eyes and whole-screen AOIs, and the looking time of the eyes AOI was divided by that of the whole-screen AOI to get the relative looking time for eyes AOI. Second, we evaluated whether participants were looking at the eye region during or shortly after the gaze shift, so that the heart rate deceleration within the following 2-sec heart rate analysis period could be
linked to the observed eye gaze stimulus. The latencies for entering the eyes AOI after the gaze shift was calculated. If the gaze was already in the AOI, the latency was given a value of 0. Then, we analysed the proportion of trials (in relation to the total number of trials) in which the gaze entered the eyes AOI within the first 500 ms.

Data from the two gaze conditions were analysed both separately and combined across the different gaze directions. A minimum of two trials per condition was required to include a participant in the analysis. The rejection was made separately for each analysis to include the maximum amount of data. The average number of accepted trials for the first analysis (looking time) was 8.3 (SD = 6.2) in the ASD, 11.6 (SD = 5.2) in the TD, and 10.3 (SD = 5.0) in the DD group. The respective numbers for the second analysis (proportion of trials in which the gaze entered the eyes AOI within the first 500 ms) were 8.4 (SD = 6.1) in the ASD, 11.2 (SD = 5.3) in the TD, and 9.9 (SD = 5.0) in the DD group. Differences between the groups were not statistically significant.

Statistical Analysis

The statistical analyses were performed with R 3.2.4-revised [R Core Team, 2016] and SPSS 21. First, a split-plot analysis of variance (ANOVA) was performed on heart rate change scores with Gaze (direct, averted) and Time (0–500 ms, 500–1000 ms, 1000–1500 ms, 1500–2000 ms) as within-subjects variables and Group (ASD, TD, DD) as between-subject variable. Given the small sample size, permutation tests were used to verify the findings. These tests were run with the function “aovp” of the R package lmPerm [Wheeler, 2010]. The function projects the observations into error strata such that each stratum has a single error term, and permutes the projected values within each stratum. For example, the significance of the Group factor can be tested by making permutations in the subject error stratum. For more details on error strata, see p. 195 in Venables and Ripley [1999]. The observed test statistic is compared to the test statistics of the permutations, and the P-value describes the proportion of the permutations having a more extreme test statistic than the observed test statistic. We set the relative standard error of 0.01 for the P-value, which required over ten million iterations for the Group × Gaze interaction (additional parameters: maxIter = 1e8 and Ca = 0.01). As the normality assumption for the data was met, the planned pair-wise comparisons were performed with t-tests without corrections. Due to non-normal distributions, the analysis of the gaze data was performed using Kruskal–Wallis test, Wilcoxon sign rank test (differences between direct and averted gaze condition within the groups), or, when the symmetry assumption was not met, the exact sign tests.

Results

Heart Rate

The ANOVA (Gaze × Time × Group) and the permutation test revealed a significant interaction between Gaze and Group, \( F(2,42) = 6.44, P = .004, \eta_p^2 = .235 \), permuted \( P = .004 \). No other significant effects were found. Paired t-tests for the mean heart rate change over time showed that the heart rate deceleration was greater in the direct than averted gaze condition in both TD (direct \( M = -1.12 \) bpm, SD = 2.40, averted \( M = 1.03 \) bpm, SD = 2.24, \( t(16) = 2.93, P = .01 \)) and DD (direct \( M = -0.71 \) bpm, SD = 3.06, averted \( M = 1.82 \) bpm, SD = 3.30, \( t(15) = 2.19, P = .044 \)) groups. In the ASD group, the heart rate decelerated in response to averted gaze (\( M = -1.31 \) bpm, SD = 3.27), whereas a slight heart rate acceleration occurred to direct gaze (\( M = 1.39 \) bpm, SD = 2.41); the difference between these conditions approached significance, \( t(11) = 1.90, P = .084 \) (Figs. 3 and 4).
Looking Time and Frequency

The median relative looking time of the eyes AOI (relative to the looking time of the whole screen AOI) did not differ between groups, either when analysed across all trials or when direct and averted gaze conditions were analysed separately (see Table II). The Wilcoxon signed rank test showed no differences in the relative eyes AOI looking time between direct and averted gaze conditions either; neither when analysed for all participants (\(z = -0.58, P = .561\)), nor when analysed for each group separately (ASD: \(z = 0.42, P = .674\); TD: \(z = -1.01, P = .311\); DD: \(z = -0.63, P = .530\)).

Discussion

In this study, we investigated orienting response, measured as heart rate deceleration, to dynamic shifts of direct versus averted gaze in young low-functioning children with severe ASD and chronologically and developmentally age-matched controls. We predicted to find a greater heart rate deceleration response to direct than to averted gaze in the TD and DD children but not in the children with ASD. The results supported this hypothesis.

The present findings showed that the 2–5-year-old children without ASD (both TD and DD) responded to the direct gaze with an enhanced orienting response, which is in accordance with previous results observed in adults [Akechi et al., 2013; Myllyneva & Hietanen, 2015]. In addition, our findings agree with several behavioural studies demonstrating the strong capacity of direct gaze to capture attention in infancy [Farroni et al., 2002], childhood [Senju et al., 2005a], and adulthood [Böckler et al., 2014; Conty et al., 2006; Doi et al., 2009; Von Grünau & Anston, 1995; Papanicola & Itier, 2012; Senju & Hasegawa, 2005; Senju et al., 2005a].
current heart rate measurement study expands these behavioral findings by showing that attention capture by direct gaze, which manifests as fast stimulus detection, is accompanied by a physiological orienting response that enhances a deeper exploration of the socially salient stimulus [cf. Öhman et al., 2000].

The results did not show an enhanced heart rate orienting response to direct gaze compared to averted gaze in low-functioning children with ASD. This finding supports the hypothesis of passive omission of direct gaze in ASD [cf. Senju & Johnson, 2009]. Our task was designed so that the children would easily detect the movement of the eyes, and the eye tracking data confirmed that the lack of heart rate deceleration response in children with ASD was not caused by not looking at the eye region. Thus, as the heart rate results cannot be explained by a lack of perceptual registration of the eyes, we suggest that they reflect a lack of social signal value of direct gaze. In this respect, our result broadens the findings of previous studies using visual search paradigms [Senju et al., 2003; Senju et al., 2005a], by showing that children with ASD not only seem to lack the perceptual detection advantage of direct gaze but also fail to respond to the perceived direct gaze with enhanced physiological orienting. Our results are also supported by previous studies using brain response measurements indicating no enhancement of attention-related ERP components to direct versus averted gaze in school-aged children with ASD [Senju et al. 2005b].

The specific value of the current study is its focus on young low-functioning children with severe ASD who are not well represented in the field of psychophysiological autism research. Studies with school-aged high-functioning children with ASD have shown that they respond to direct versus other gaze directions with enhanced arousal responses [Kylliainen & Hietanen, 2006; Kylliäinen et al., 2012; Stagg, Davis, & Heaton, 2013], which has been regarded as evidence for the hypothesis that the lack of eye contact was caused by enhanced, negatively valenced arousal responses to direct gaze that lead to active avoidance of eye contact [e.g., Bowman, Hinkley, Barnes, and Lindsay, 2004; Dalton et al., 2005; Hutt & Ounsted, 1966; Skuse, 2003; Tanaka & Sung, 2013]. However, the enhanced arousal response to eye contact in school-aged children with ASD might be caused by fewer experiences in eye-to-eye communication or due to anxiety caused by the developing awareness of the social demands related to eye contact. Nuske, Vivanti, and Dissanayake [2015] measured pupil dilation responses as a measure of arousal to facial pictures with direct versus averted gaze and found no differences in pupil responses between 2–5-year-old children with ASD (both low- and high-functioning) and their age-matched TD controls. Together with Nuske et al.’s [2015] study, this heart rate results seem to provide support for the hypothesis that the primary cause for diminished eye contact behaviour in children with ASD could be the passive omission of social signals related to eye gaze rather than the elevated, negatively valenced arousal responses. It should be noted, however, that we did not measure arousal in our study, and that the hypotheses postulating omission and avoidance of eye contact do not need to be mutually exclusive. Different individuals within the autism spectrum or even the same children in different situations might respond differently to direct gaze already in their development. Children’s cognitive abilities may have an effect on psychophysiological responses to eye gaze, although this effect might be more apparent later in the development because of learning of compensatory strategies. For example, in their abovementioned study, Nuske et al. (2015) did not find a correlation between cognitive abilities and visual attention or pupil responses in their sample of young children with ASD. Cognitive development is, however, correlated with symptom severity [Bitsika, Sharpley, & Orapeleng, 2008], which might have an effect on the responses to eye gaze [Joseph et al., 2008; Kaartinen et al., 2012; Kaartinen et al., 2016; Stagg et al., 2013]. Taken together, investigating a wide range of developmental stages and children with different degrees of severity of ASD symptoms is needed to understand eye contact difficulties.

An apparent limitation of this study was the small sample size and loss of data related to the young age and developmental difficulties (e.g., short attention span and motor restlessness) of our participants. The data quality was ensured by careful offline video analyses to reject contaminated trials, although this led to a loss of participants and trials. The fact that the permutation tests showed results similar to those obtained with ANOVA F-tests confirms the reliability of the present findings. However, further replications of our study are warranted.

In TD and DD children, differential heart rate deceleration was found in response to illusory (i.e., change between two static images) dynamic shifts of eye gaze. In contrary, Louwerse et al. [2013] did not find differential heart rate responses to direct versus averted gaze in TD adolescents (nor in adolescents with ASD) when using still images. This discrepancy between studies could be explained by the different age and ability level of participants but also by the differences between stimuli. There is experimental evidence with adult participants that the use of still images does not yield differential physiological responses to different gaze directions, whereas using a live person (with static gaze) does [e.g., Hietanen, Lepänen, Peltola, Linna-Aho, & Ruuhiala, 2008; Pönkänen, Peltola, & Hietanen, 2011]. In line with this notion, two studies that reported enhanced heart rate deceleration to direct versus averted gaze [Akechi et al., 2013; Myllyneva
& Hietanen, 2015] used live persons as stimuli. In this task, the illusion of the eye gaze shift might have made the stimuli more realistic, thus, more closely resembling “live” stimuli. Alternatively, our task might have been more sensitive to reveal the effect of gaze direction, because the measurement of the heart rate deceleration was time-locked to the shift in eye gaze instead of the appearance of the face stimulus as in previous studies. Previous research [cf. Saitovitch et al., 2013] also recommended the use of dynamic stimuli when studying abnormalities in social cognition of special populations. Thus, more studies with dynamic and live stimuli are needed to investigate, whether children and adolescents with and without ASD show enhanced orientation to direct verses other gaze direction.

To summarize, young children with typical development and developmental delay without ASD showed enhanced physiological orienting response to direct gaze (vs. averted gaze). In contrast, no enhanced orienting response to direct gaze was found in young low-functioning children with ASD. In everyday life situations, a lack of readiness to orient and engage attention to direct gaze probably leads to ignoring of signals that often indicate other persons’ intentions to communicate. The lack of engagement with these signals might have far-reaching consequences for the development of social interaction skills. This study also suggests that using psychophysiological measures improves understanding of the nature of abnormal eye contact behavior in children with ASD who lack the ability to describe their thoughts in words. This understanding is essential in planning directions for rehabilitation. If shifts of other individuals’ gaze direction are not socially salient for children with ASD, we need to establish ways to help these children learn to pay attention to the eyes and increase the likelihood to respond to direct gaze.

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