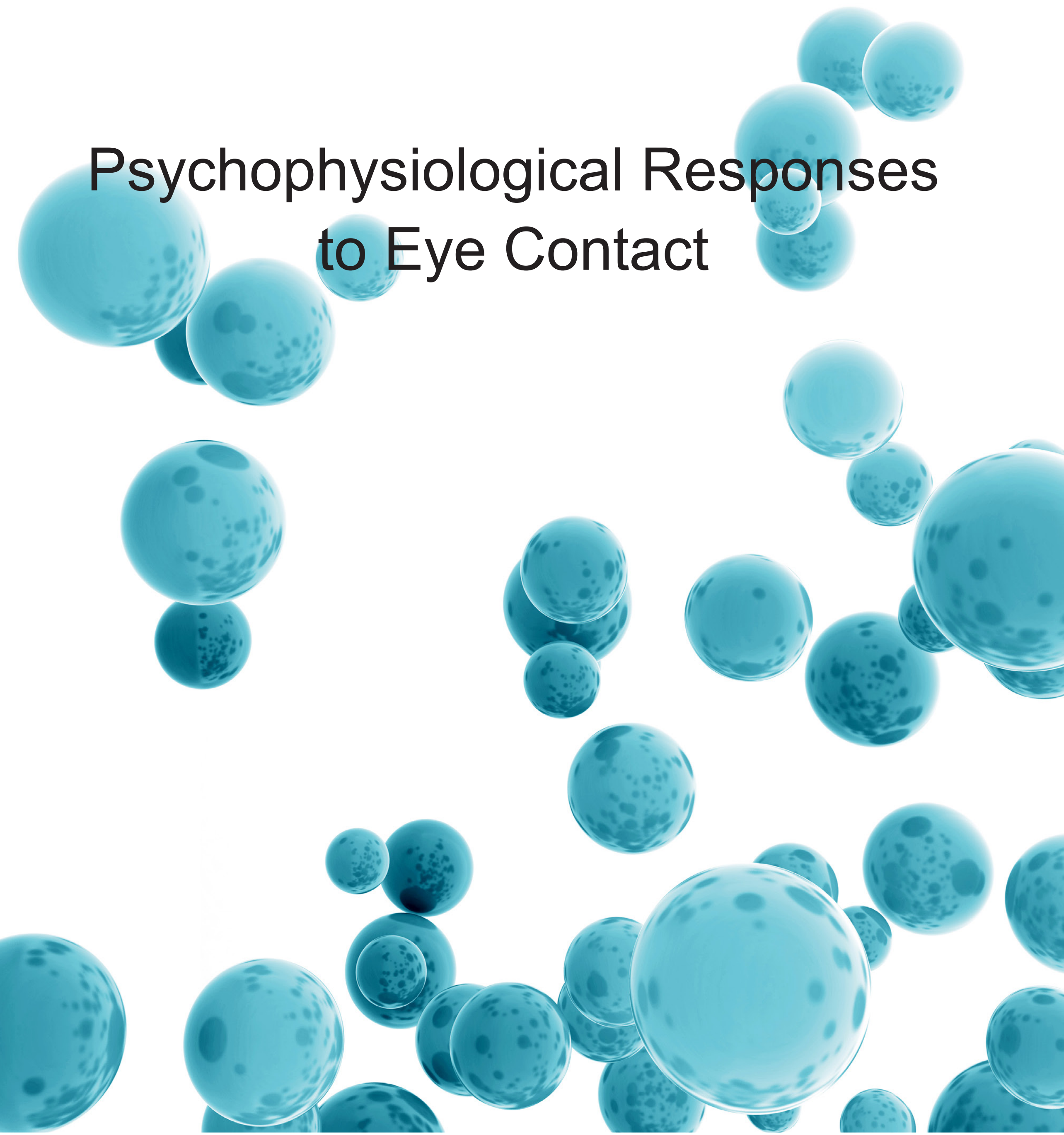
Acta Universitatis Tamperensis 2196

AKI MYLLYNEVA

Psychophysiological Responses to Eye Contact



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ACADEMIC DISSERTATION
To be presented, with the permission of
the Board of the School of Social Sciences and Humanities
of the University of Tampere,
for public discussion in the lecture hall Linna K 103,
Kalevantie 5, Tampere,
on 2 September 2016, at 12 o'clock.

UNIVERSITY OF TAMPERE

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Tampere University Press
Tampere 2016

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University of Tampere
School of Social Sciences and Humanities
Finland

The originality of this thesis has been checked using the Turnitin OriginalityCheck service in accordance with the quality management system of the University of Tampere.

Cover design by
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Distributor:
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https://verkkokauppa.juvenes.fi

Acta Universitatis Tamperensis 2196
ISBN 978-952-03-0192-7 (print)
ISSN-L 1455-1616
ISSN 1455-1616

Acta Electronica Universitatis Tamperensis 1695
ISBN 978-952-03-0193-4 (pdf)
ISSN 1456-954X
http://tampub.uta.fi

Suomen Yliopistopaino Oy – Juvenes Print
Tampere 2016

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to professor Jari Hietanen, my supervisor, who expertly guided me through the graduate studies. Thank you for giving me the opportunity to take part in the fascinating work in your laboratory. I could always rely on that you have time and energy to listen what I have in mind or read my work, and give painstakingly detailed and sharp comments. I am not the only one who knows that Jari's door is always open for his students and I have always felt that help and support is available when needed. Thanks Jari!

I would also like to thank my other supervisor, doctor Anneli Kylliäinen for guidance and support. I give a great appreciation to how you have shown me - by numerous discussions and courses, and by your own example - how research and clinical work can be put together in a fruitful and meaningful way. When I had research related problems, you had advice and direction to show me, when I went through difficult times and struggled with doubt and uncertainty, you had time to listen, and told me it's going to be allright. It mattered a lot.

I am thankful to professor Kimmo Alho and doctor Laurence Conty for reviewing this thesis and providing constructive evaluation. Doctor Conty additionally accepted the invitation to be the opponent of which I am also grateful for.

All the studies were conducted in Human Information Processing laboratory, University of Tampere. I would like to thank Mikko, Pessi, Tingji, Hiro, Laura, Ilkka and other researchers and students who have worked in the laboratory during last years. Especially I would like to thank Terhi, with whom I not only shared the working environment, but also the joys and troubles of learning to do science. It has been a priviledge having had a friend and colleague like you to take this journey with.

I am thankful to docent Klaus Ranta for collaboration, guidance and support during the long and laborous social anxiety project.

I would like to thank the School of Social Sciences and Humanities, and the psychology section in particular, for providing an exellent and insipiring working community.

I have had a fortune of being able to work in many clinics during this dissertation project. Numerous exeperienced professionals have used their valuable time to guide, advice, and encourage me in my first steps trying to put to use my knowledge in the clinical world. I would like to thank my colleagues and other professionals in the Division of Child Neurology and the Clinic of Phoniatrics in Tampere University Hospital, Tampereen yliopiston opetus- ja tutkimusklinikka PSYKE, and Neuropsykologipalvelu Frontaali Oy.

I would like to express my gratitude to my family and friends for support during last years and for valuable time out of academic questions. Finally, I would like to thank Sanna for understanding and solidarity through good and bad times.

ABSTRACT

Eye contact is an essential social cue. Recent studies have shown enhanced brain, autonomic, and self-assessed responses to making eye contact with a person. Interestingly, greater responses to eye contact than an averted gaze have been observed when showing live faces as stimuli, but not when showing pictures of faces on a computer screen. The present studies investigate how two components of eye contact - seeing and being seen - affect bodily and self-assessed responses. We also studied how adolescents with social anxiety disorder are affected by eye contact when they not only see the other person, but are also seen.

Study Ia indicates that eye contact results in greater autonomic, brain, and self-assessed responses compared to averted gaze if one believes that the other person is able to see him or her. Study Ib shows that seeing the other person's eyes is not the key element in the bodily responses associated with eye contact, whereas the knowledge of being seen by the other person is. Study II indicates that when not seeing another person at all, only the knowledge of being seen by another person does not elicit similar bodily responses as when one makes natural eye contact. Finally, Study III shows that adolescents with social anxiety disorder (SAD) exhibit a consistent physiological, behavioral, and self-assessed response pattern characterizing the core symptoms of SAD when making eye contact with a live person.

The results suggest that contextual factors are powerful modulators of the processing of socially relevant sensory information. Especially important is the knowledge or the belief that the other person can see the observer. Two requirements must be met for physiological responses to occur in response to eye contact: the experience of being seen by another individual, and the experience of seeing the other individual.

TIIVISTELMÄ

Katsekontakti on tärkeä sosiaalinen signaali. Tutkimukset ovat näyttäneet, että katsekontaktitilanteessa havaitaan lisääntynyttä aktiivisuutta tietyissä aivo- ja autonomisen hermoston vasteissa. Katsekontaktin vaikutus on tullut esiin myös itsearvioinneissa. Mielenkiintoista on se, että katsekontaktin aiheuttamia voimistuneita reaktioita on tullut esiin tutkimuksissa vain kohdattaessa oikea ihminen, mutta ei nähtäessä toisen ihmisen kuva. Tämän työn tutkimuksissa selvitetään kuinka kaksi katsekontaktiin kuuluvaa osaa - näkeminen ja nähdyksi tuleminen - vaikuttavat kehon reaktioihin ja itsearviointeihin. Tässä työssä selvitellään myös katsekontaktin vaikutusta sosiaalisen tilanteen pelosta kärsiviin nuoriin.

Tutkimus Ia näytti, että katsekontakti aiheuttaa voimistuneita aivovasteita sekä autonomisia- ja itsearvioituja reaktioita verrattuna käännetyn katseen näkemiseen, mutta vain mikäli ihminen uskoo toisen ihmisen kykenevän näkemään hänet. Tutkimus Ib osoitti, että toisen ihmisen silmien näkeminen sinänsä ei ole oleellista voimistuneiden reaktioiden syntymiselle, vaan tietoisuus nähdyksi tulemisesta. Kuitenkin tutkimuksessa II näytettiin, että mikäli toinen ihminen on täysin poissa näkyvistä, pelkästään uskomus nähdyksi tulemisesta ei aiheuta samankaltaisia fysiologisia ja itsearvioituja reaktioita kuin toisen ihmisen kohtaaminen luonnollisessa katsekontaktitilanteessa. Lopuksi, tutkimuksessa III selvitettiin sosiaalisen tilanteen pelosta kärsivien nuorten fysiologisia, käyttäytymiseen liittyviä ja itsearvioituja reaktioita katsekontaktitilanteessa oikean ihmisen kanssa.

Tulokset viittaavat siihen, että kontekstuaaliset tekijät moduloivat voimakkaasti sosiaalisesti tärkeän aistitiedon käsittelyä. Erityisen tärkeä rooli näyttää olevan uskomuksella siitä kykeneekö toinen ihminen näkemään katsojan vai ei. Kaksi erillistä ehtoa täytyy toteutua, jotta keho reagoisi katsekontaktiin asianmukaisella tavalla: kokemus toisen ihmisen näkemisestä ja uskomus nähdyksi tulemisesta.

CONTENTS

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.

I. Myllyneva, A., & Hietanen, J. K. (2015). There is more to eye contact than meets the eye. *Cognition*, *134*, 100-109.

II. Myllyneva, A., & Hietanen, J. K. (2015). The dual nature of eye contact: to see and to be seen. *Social Cognitive and Affective Neuroscience,* doi: 10.1093/scan/nsv075.

III. Myllyneva, A., Ranta, K., & Hietanen, J. K. (2015). Psychophysiological responses to eye contact in adolescents with social anxiety disorder. *Biological Psychology*, 109, 151–158.

1 INTRODUCTION

Eye contact has very important functions in human interaction. A common proverb states that "eyes are the window to the soul", and William Henry has been quoted as saying "the eyes shout what lips fear to say". Both of these phrases describe the communicative potential of the eyes. The human eye is unique among those of primates in its morphology, which enables efficient communication through gaze signals (Kobayashi & Kohshima, 1997). Encountering a face with a direct gaze grabs and holds attention and facilitates perception, discrimination, and memory of facial information (for a review, see Senju & Johnson, 2009). Gaze is used in initiating and regulating interactions (Argyle, 1988; Kleinke, 1986). It has been suggested that exchanging gazes in a community serves to maintain social bonds and enables the forming of alliances in a similar manner as social grooming does for many primates (Kobayashi & Hashiya, 2011). The sensitivity to gaze signals seems to be innate, as even newborns gaze longer at faces making eye contact than at those with an averted gaze (Farroni, Csibra, Simon, & Johnson, 2002). Overall, people seem to expect other people's eyes to be directed at them (Mareschal, Calder, Clifford, 2013). Reading gaze signals is, however, susceptible to situational and personal factors. For example, compared with non-anxious controls, people with social phobia are more prone to interpreting slightly ambiguous gazes as being directed at them (Gamer, Hecht, Seipp, & Hiller, 2011).

All these cognitive and behavioral phenomena are, naturally, reflected in the functioning of our nervous system. The human brain is exceptionally large compared to the human body size. It has been hypothesized that the main reasons for this are the demands of living in complex societies (Dunbar & Shultz, 2007). This suggests that a major part of the human cortex is used to process social information. Important sources of such information are the conspecifics' eyes. The main goal of this work was to try to tackle certain questions regarding how eye contact is reflected in central and autonomic nervous system functions using data from electroencephalography (EEG), skin conductance responses (SCR), and heart rate (HR). In addition, behavioral and self-assessed measures will be used. I will begin by reviewing what is known about these measures and other relevant issues from earlier research and then return to the questions posed in the present work.

1.1 The effects of eye contact on autonomic responses

The autonomic nervous system regulates many vital bodily activities, including body temperature, digestion, and blood pressure. The sympathetic branch of the autonomic nervous system causes bodily changes that prepare the body for action (increased blood sugar, enhanced blood flow, dilation of the pupil). On the other hand, the parasympathetic branch is activated during rest, repair, and relaxation. The polyvagal theory (Porges, 2001) proposes that the autonomic nervous system operates in a hierarchical manner. Phylogenetically, the most recently developed and most elaborate system is the ventral vagal complex (VVC). It is parasympathetically mediated and is the primary operator during emotion and communication. The second subsystem is the sympathetic nervous system (SNS), operating when more action is required. The last subsystem consists of the dorsal vagal complex (DVC), which is responsible for behaviors such as freezing. The activity of the autonomic nervous system can be measured using various methods. Here I concentrate on two important measures of the autonomic system: the SCR, and the HR deceleration response. The SCR is an index of sympathetic affective arousal (Dawson, Schell, & Filion, 2000). The activity of the sympathetically mediated eccrine sweat glands affects how electricity travels on the skin, and fluctuations in conductance, resistance, or potential are related to changes in states of arousal, emotion, and motivation (Andreassi, 2000; Figner & Murphy, 2011). It has been suggested that electrodermal activity is controlled by three systems in the brain that are related to emotion, arousal, and locomotion. The first of these is controlled by limbic structures, the second by the reticular formation, and the third by the motor cortex and basal ganglia (Boucsein, 2012). SCRs have been shown to be related to stimulus significance, as well as stimulus novelty (Bradley, 2009).

According to the polyvagal theory, changes in heartbeat during social situations occur predominantly through the parasympathetic pathway via the VVC (Porges, 2001). Most changes in HR due to parasympathetic activation occur very rapidly, with peak effects seen in about 0.5 seconds and a return to baseline within 1 second. In contrast, sympathetically mediated changes have peak effects at about 4 seconds and a return to baseline after about 20 seconds

(Berntson et al., 1997). The relatively slow HR deceleration response during perception is predominantly parasympathetically mediated and is a very important marker of attention. It was first reported by Graham and Clifton (1966) and Lacey (1967), who observed that the heartbeat decelerates for several seconds very soon after attending to a stimulus. It has been suggested that the deceleration of the HR is related to sensory intake (orienting response), whereas HR acceleration is related to sensory rejection (defense response) (Graham, 1979). The HR deceleration effect is controlled by the parasympathetic system via the vagus nerve and the acceleration effect is mostly influenced by the sympathetic nervous system (Andreassi, 2000). However, HR acceleration can also be due to decreased parasympathetic activity (Andreassi, 2000).

There are some previous studies investigating the effect of eye contact on SCR and/or HR. It has been shown that sharing eye contact with another person results in larger SCRs than facing a person who is looking aside during a prolonged exposure (Helminen et al., 2015; Nichols & Champness, 1971), as well as during relatively short viewings (Helminen et al., 2011). Larger SCRs have also been observed while viewing eye images with direct versus averted gazes during a cognitive task (Conty, Gimmig, Belletier, George, Huguet, 2010). Stronger HR deceleration responses have been observed when viewing a person making eye contact than when seeing a person without eye contact (Akechi, Senju, Uibo, Kikuchi, Hasegawa, & Hietanen, 2013). On the other hand, higher HRs have been reported during a game session when encountering a player making eye contact versus one without eye contact (Kleinke & Pohlen, 1971). There are no discrepancies between these two observations, however, when one considers HR deceleration and acceleration responses to eye contact. They together suggest that eye contact leads to a strong orienting response and then, if prolonged, a heightened HR.

1.2 The effects of eye contact on information processing in the brain

Neuroimaging studies have revealed stronger activation in response to faces making eye contact than those without eye contact in several brain areas, including the fusiform gyrus (Calder et al., 2002; George, Driver, & Nolan, 2001; Pageler, Menon, Merin, Eliez, Brown, & Reiss, 2003), superior temporal sulcus (Calder et al., 2002; Wicker, Perrett, Baron-Cohen, & Decety, 2003), medial prefrontal cortex (Schilbach et al., 2006), orbitofrontal cortex (Conty, N´Diaye, Tijus, & George, 2007; Wicker et al., 2003), and amygdala (Kawashima et al., 1999; Sato, Yoshikawa, Kachiyama, & Matsumura, 2004). It has been shown that the human amygdala is activated more strongly in response to direct vs. averted gazes, even if the individual lacks conscious visual experience because of the destruction of the primary visual cortex (i.e., cortical blindness; Burra, Hervais-Adelman, Kerzel, Tamietto, De Gelder, & Pegna 2013). Recently it was shown that the monkey amygdala contains neurons that respond selectively to eye contact (Mosher, Zimmerman, & Gothard, 2014). However, the role of amygdala in gaze processing is still under dispute. For example, in a recent study, neurons responding selectively to eye contact or gaze direction were not found in the human amygdala, and it was suggested that gaze processing in humans draws predominantly on cortical networks (Mormann et al., 2015).

EEG offers various measures for the investigation of brain activity in relation to eye contact. Event-related potentials (ERPs) are signal-averaged, time-locked epochs of EEG, some of which have been shown to be related to face processing and/or eye contact. The N170 response and the early centro-parietal and lateral occipito-temporal responses are relatively early ERP components known to reflect face processing (Bentin, Allison, Puce, Perez, & McCarthy, 1996; Sams, Hietanen, Hari, Ilmoniemi, & Lounasmaa, 1997). These responses have also been shown to be sensitive to gaze direction (Conty, N'Diaye, Tijus, & George, 2007; Pönkänen, Alhoniemi, Leppänen, & Hietanen, 2011). Another early ERP component, early posterior negativity (EPN), has been shown to be enhanced in response to attended and motivationally significant stimuli (Schupp, Stockburger, Codispoti, Junghöfer, Weike, & Hamm, 2007; Codispoti, Ferrari, Junghöfer, & Schupp, 2006) and has also been demonstrated to differentiate between faces with direct versus averted gazes (Pönkänen et al. 2011).

An interesting ERP component is the frontal P3a, which arises slightly later than the previously mentioned responses. P3a is associated with initial target stimulus processing, is related to novelty and attentional focus (Kok, 2001; Polich, 2007; Knight, 1997), and is hypothesized to be associated with the functioning of dopaminergic pathways (a review, Polich, 2007). It is also modulated by the emotional content of the stimulus (Cuthbert, Schupp, Bradley, Birdbaumer, & Lang, 2000). Conty et al. (2007) studied P3a by showing participants faces that initially had a slightly averted orientation and gaze. The gaze direction of the shown faces changed either towards the observer (direct gaze) or further away from the observer (averted gaze). The researchers analyzed P3a beginning at the time of the shift of the gaze direction. They observed P3a to be more positive when the subject saw dynamic gaze shifts resulting in a direct gaze compared to an averted gaze. The authors suggested that this reflects attentional and emotional processes associated with seeing a face that is gazing at us.

It has been shown that direct and averted gazes can induce approach and avoidance motivations, respectively (Adams & Kleck, 2003, 2005). Using EEG, one can investigate asymmetries in frontal brain activity, which have been associated with approach and avoidance motivations. Stronger relative left-sided versus right-sided frontal activity is shown to be associated with the activation of the approach-motivation system and positive emotion, whereas stronger right-sided vs. left-sided activity has been associated with the activation of the avoidance-motivation system and negative emotion (Davidson, 2004; Harmon-Jones, 2003; Van Honk & Schutter, 2006). It has been shown that seeing another person making eye contact results in more pronounced left-sided, approach-related frontal activity in the perceiver's brain than seeing a person who is gazing aside (Hietanen et al., 2008; Pönkänen, Peltola, Hietanen, 2011). Interestingly, stronger relative left-sided activity in response to direct gaze vs. closed eyes has been observed in typically developing children, but not in children with autism spectrum disorder (Kylliäinen et al., 2012).

1.3 Ecological validity in stimulus presentation

In recent years, researchers working in the field of social cognition and social neuroscience have become aware that studying social cognition in the laboratory by showing images of other people to passive observers barely touches upon the psychological processes activated when another person is actually present. Researchers have started to ask if the functioning of the social brain network and the associated psychological and physiological responses are the same when the experimental participants are looking at a picture vs. encountering a real person. Furthermore, if differences do exist, what kind of psychological and neural mechanisms are responsible for this modulation (Risko, Laidlaw, Freeth, Foulsham, & Kingstone, 2012; Schilbach et al., 2013; Teufel, Fletcher, & Davis, 2010; Hietanen, Leppänen, Peltola, Linna-aho, & Ruuhiala, 2008)? Elaborating on the most important arguments of recent review articles, Risko et al. (2012)

pointed out that knowledge regarding the social brain gained using non-interactive stimuli may not generalize to the richer scenarios associated with everyday interactive social cognition. Teufel et al. (2013) suggested that observers viewing pictures may not attribute current mental states to the stimuli or might do so in a qualitatively different way than they would in a real interactive situation. Finally, in a comprehensive, seminal article, Schilbach et al. (2013) called for studies including real-time social encounters in a truly interactive manner and named the neural mechanisms underlying social encounters as the "dark matter" of social neuroscience.

There is, however, some knowledge regarding how interaction-related issues may affect social cognition. Several researchers have shown that visual attention orienting by gaze direction cues is modulated by the interactive potential of the situation, such as the those determined by the openness of the observed agent's eyes (closed or open) (Nuku & Bekkering, 2008), the belief of whether the observed person can or cannot see (Teufel, Alexis, Clayton, & Davis, 2010), and the belief of whether the observed agent’s gaze is intentional or not (Wiese, Wykowska, Zwickel, & Müller, 2012). In addition, sensory visual adaptation to gaze direction stimuli has been shown to be modulated by the mental-state attributions of the observer (Teufel et al., 2009).

There is also evidence suggesting that an individual's gazing behavior differentiates between situations where there is a potential to interact versus those where there is no potential to interact. People walking through a university campus (wearing a mobile eye tracker including a video camera) displayed different gazing behavior than those viewing the video of the same trip (Foulsam, Walker, & Kingstone, 2011). More specifically, when being near to another person (thus having a potential for interaction), people adjust their gazing behavior by looking elsewhere more often in the real walk situation than when watching the video. In another experiment, people sitting in a waiting room displayed very different gazing patterns depending on whether a real person or a video recording of the same person was placed in the room (Laidlaw, Foulsham, Kuhn, & Kingstone 2011). The authors suggested that individuals’ gaze patterns change depending on whether the attentional objects represent real social agents (for whom the actions of the observer would have meaning).

A series of studies reported differences in physiological, as well as subjective, evaluative responses to seeing a picture of a person on a computer monitor versus seeing a person “live” through a liquid crystal (LC) window.

These studies revealed effects that have been mostly described before: eye contact with another person was shown to elicit larger SCRs (Hietanen et al., 2008; Pönkänen, Peltola, & Hietanen, 2011), larger N170 and EPN ERP responses (Pönkänen, Alhoniemi, Leppänen, & Hietanen, 2011), and a more pronounced left-sided frontal EEG alpha-asymmetry (Hietanen et al., 2008; Pönkänen, Peltola, et al., 2011) compared to seeing a person who is looking aside. Additionally, the subjective evaluations indicated more self-assessed arousal (Hietanen et al., 2008) and higher public self-awareness (Pönkänen, Peltola, et al., 2011) for a direct gaze compared to an averted gaze. What was novel in these experiments was that participants saw the observed person in two different situations: "live" through an LC window, and on a computer monitor. The responses were recorded during both these presentation conditions and, crucially, all these effects were observed only when seeing a real live person, and not when seeing a picture on a computer screen. Worth mentioning is that there are some studies reporting no differences induced by different gaze directions on autonomic measures (e.g. Leavitt & Donovan, 1979; Joseph, Ehrman, McNally, & Keehn, 2008; Kampe, Frith, & Frith, 2003). One reason for not observing any effects may be that these studies used pictures or videos as stimuli, which are objects that are unable to look back or to interact with the observer. Notably, the previously mentioned results regarding stronger HR responses to direct versus averted gazes (Akechi et al., 2013; Kleinke & Pohlen, 1971) used real persons as stimuli. The evidence is not completely unequivocal (for a review of early findings, see Kleinke, 1986), but there is a trend suggesting that autonomic and brain responses are quite different when observing a live person vs. when seeing a picture or a video. The findings indicate that a direct gaze results in more pronounced effects only when the observer knows that he/she is being looked at by another "mind". This kind of mentalizing does not occur when facing an image or a non-living stimulus, at least not to the same degree as when facing another "live" person. It has become apparent that social perception is not only about perception of the agent, but also about making inferences regarding the mind of the agent.

1.4 Eye contact and social anxiety

Social anxiety is commonly defined as feelings of uneasiness arising when an individual interacts with others and anticipates the possibility of being negatively evaluated. The clinical form of social anxiety, social anxiety disorder (SAD), typically emerges between early and late adolescence, with a mean age of onset between 10 and 16 years (Wittchen & Fehm, 2001). Cognitive-behavioral models of social anxiety suggest that negative self-appraisals in social situations are pivotal to the development and maintenance of social anxiety (Clark & Wells, 1995; Rapee & Heimberg, 1997). It has been proposed that social anxiety is associated with approach-avoidance conflicts resulting, on one hand, from increased investment in peer relationships in adolescence, and on the other hand, from a fear of humiliation and embarrassment aroused by peer evaluation (Caouette & Guyer, 2014).

Eye contact signals that another person's attention is directed to you, which may cause a potential threat to people with social anxiety. Clinical perspectives suggest that avoidance of eye contact is one prominent symptom of SAD (Greist, 1994). Experimental evidence partly supports this: shortened viewing times of the eye region or reduced eye contact has been observed in people with social anxiety when compared to non-anxious people (Daly, 1978; Farabee, Holcom, Ramsey, & Cole, 1993; Garner, Mogg, & Bradley, 2006; Moukheiber et al., 2010). However, not all experiments have found such an effect (Hofmann, Gerlach, Wender, & Roth, 1997; Wieser, Pauli, Alpers, & Mühlberger, 2009). Some researchers have tried to explain these discrepancies using the hypervigilance-avoidance hypothesis, which states that anxious individuals initially attend to, but subsequently avoid, threatening stimuli (Wieser, Pauli, Weyers, Alpers, & Mühlberger, 2009).

Brain imaging studies have found abnormalities in amygdala activation (Stein, Goldin, Sareen, Zorrilla, & Brown, 2002; Phan, Fizgerald, Nathan, & Tancer, 2006), as well as abnormalities in the activation of the prefrontal, striatal, and parietal areas (Freitas-Ferrari, et al., 2009; Labuschagne et al. 2012) in patients with social anxiety compared to their non-anxious counterparts. A recent study indicated that SAD is associated with dysfunctions of the amygdala–prefrontal emotion regulation network caused by a reduction of prefrontal control over amygdalar activation (Sladky et al., 2015). In resting state EEG measurements, individuals with social anxiety have been shown to exhibit elevated right-sided, avoidance-related frontal activity under social stress (Davidson, Marshall, Tomarken, & Henriques, 2000). However, there are not many studies regarding physiological responses to eye contact in socially anxious participants. Wieser, Pauli, Alpers et al. (2009) found more pronounced HR acceleration in participants scoring high on social anxiety tests in response to a direct vs. an averted gaze. This difference was reversed in the group with medium scores and was non-existing in the low social anxiety group. They also measured SCR, but did not find differences in its response to direct versus averted gazes in any of the groups. The study by Wieser, Pauli, Alpers et al. (2009) used sequenced animated faces as stimuli, which are obviously not able to look back at the observer. This may have potentially had an effect on the results. Another study found a higher P100 ERP response and enhanced late positive potential responses to averted eye gazes in participants with high versus low social anxiety (Schmitz, Scheel, Rigon, Gross, & Blechert, 2012). The authors suggested that this may indicate an attentional bias to averted gazes - a potential sign of disinterest - among people with social anxiety. All in all, studies investigating physiological responses to eye contact versus averted gazes in social anxiety are very scarce, and studies investigating it in a natural context with the potential to interact with the stimulus, non-existent.

2 PRESENT STUDIES

The present studies were designed to answer two main questions. First, what causes the physiological and self-assessed responses to eye contact? According to previous research, these effects may be related to seeing another live person with his/her eyes directed (or his/her head oriented) toward you, or they may be related to the knowledge of being looked at by another person, another mind, or a combination of the two. It is also possible that autonomic, brain, and self-assessed responses are differentially sensitive to these two factors. Second, how do physiological and self-assessed responses differ between patients with SAD and healthy controls? It is well known, that patients with SAD differ from healthy controls in their behavior and their cognition in eye contact situations. However, not much is known about how their bodily responses differ. We aimed to make psychophysiological and behavioral measurements supplemented with self-assessments in participants with and without SAD in an eye contact experiment.

2.1 Psychophysiological and self-assessed responses to eye contact

It has been theorized that social perception is subserved by an interactive two-way relationship between the theory-of-mind system and the basic neural mechanisms supporting sensory processing of social information (Teufel, Fletcher, & Davis, 2010). This suggests that there is a constant feedback from the theory-of-mind system to sensory processing. In an eye contact situation, the implications are that sensory processing is affected by the higher processes evaluating, for example, the social meaning of the gaze, and the intentions of the other person. Going further, this would lead to differential processes and responses to the observation of a direct gaze in different social contexts. This, of course, makes perfect sense: seeing another person or a pair of eyes does not always mean that one is taking part in social interaction. In everyday life, we see faces with direct gazes – for example, in magazines, television and advertisements – without encountering any true interaction. It is obvious that it would not be adaptive to react similarly to an unknown face staring at you on the other side of the table and a face staring at you in a magazine.

Earlier research concerning the effects of eye contact has only rarely taken into consideration the possible differences between eye contact with someone who is able to see and think (a real person), and eye contact with somebody who is not (a picture or a video). Strictly speaking, the term "eye contact" is perhaps suitable only in the former cases, but for the sake of simplicity, I use the term "eye contact" also in the latter occasions. In the first three studies, we investigated the fundamental question of how these attributional factors influence one's bodily and self-assessed responses. The research reviewed in the introduction provides some convincing evidence that the mere visual input from a pair of eyes directed at the observer is not enough to explain the following reactions. However, it does not provide possibility to evaluate the effects of mental attributions in a systematic manner. It has been suggested that one critical factor may be whether the observer has an experience of being seen by another person and being the target of another person's attention (Hietanen et al., 2008; Pönkänen, Peltola, et al., 2011; Pönkänen, Alhoniemi et al., 2011; Pönkänen et al., 2008). This suggestion is a starting point for the present work.

In Study Ia, we aimed to isolate the influence of being seen by another person while keeping the stimulus presentation condition as natural as possible. To this end, we showed the participants a face of a live model with a direct or an averted gaze through an LC window. In one condition, the participant and the model saw each other through the LC window as usual, whereas in another condition, the participant was led to believe, by using a deception, that a half-silvered mirror was placed against the LC window in such a way that the model could not see the participant. In Study Ia, we thus investigated whether the participant's belief of whether the model could see him/her influenced the effects elicited by eye contact. We expected enhanced autonomic and brain responses to direct versus averted gaze in the condition where the participants believed they were seen by the model. Conversely, we expected the differences in the response to direct versus averted gaze to be reduced or even eliminated when the participant believed that the model was unable to see him/her.

Assuming that knowledge of being looked at is an important factor underlying enhanced physiological responses to eye contact, one can ask if seeing another's eyes is even necessary to elicit the "eye contact effect." Senju and Johnson (2009) defined the eye contact effect as "the phenomenon that perceived eye contact modulates the concurrent and/or immediately following cognitive processing and/or behavioral response". Their fast track modulator model postulates that the eye contact effect relies on the processing of visual information from the eyes by subcortical mechanisms, which then modulate cortical processing. However, one can ask what kind of effect the eyes have as visual stimuli on the results. If the critical factor is an observer's experience of being watched, then the visibility of another individual's eyes is perhaps not necessary. In Study Ib, we manipulated not only the participant's belief in the model's ability to see the participant, but also the visibility of the model's eyes. In three different experimental blocks, we addressed this question by showing the participants a live model with a direct or averted head orientation. In each block, the model wore a different pair of sunglasses: 1) a pair without lenses so that the model's eyes were visible, 2) a pair of normal sunglasses with dark lenses, and 3) a pair with blocked lenses so that the model could not see through them. If the physiological responses are dependent on seeing the eyes, we would not expect to observe differences between the direct and averted head orientations in the two conditions where the eyes are not visible. However, if the experience of being seen by another person is crucial for the enhanced autonomic responses, we would expect to observe larger responses to a direct vs. an averted head orientation regardless of the visibility of the model's eyes, so long as the observer knows that the other person is able to see him or her. We expected to observe the latter pattern of results.

In Study II, we went one further step and asked whether it is possible to observe the physiological responses to being seen by another person even when the other person is not visible at all. There is substantial evidence indicating that the autonomic nervous system can be activated without the presentation of any sensory stimuli. For example, emotional and motor imagery tasks have been shown to result in similar autonomic activation as emotional sensory stimuli or actual motor performance, respectively (for reviews, see Guillot & Collet, 2005; Kreibig, 2010; Lang, 1979). It has also been shown that mental imagery can modulate cortical activity. For example, imagining faces has been shown to produce a similar modulation of the face-sensitive N170 EEG response to that elicited by seeing actual faces (Ganis & Schendan, 2008). In the present experiment, we compared physiological and self-evaluated responses in three different experimental conditions: (1) when the participant and the model could both see each other; (2) when the participant could not see the model, but was led to believe that the model could see him/her; and (3) when the participant could not see the model and was led to believe that the model also could not see him/her. We had a straightforward hypothesis: we predicted greater autonomic and brain responses when participants thought that they were being observed compared to when they thought that they were not being observed, regardless of whether the other person was visible.

2.2 Responses to eye contact in adolescents with social anxiety disorder

In Study III, we investigated autonomic arousal and approach-avoidance-related brain activity in response to a live person with different gaze directions in adolescents with clinically diagnosed SAD and in age- and sex-matched controls. There are no previous studies measuring autonomic and brain responses to eye contact from a live person in participants with social anxiety. Given that SAD is associated with a fear of being negatively evaluated, and that such an evaluation is possible only if one is being observed by another person, it is of utmost importance to use a live person as a stimulus when investigating responses to eye contact in participants with SAD. In this experiment we aimed to fill this gap in research. We showed the participants a live face with a direct gaze, an averted gaze, or with closed eyes through an LC window, and simultaneously recorded autonomic and brain responses. Additionally, we measured the participants' preferred viewing time.

We hypothesized that all participants would show heightened sympathetic activity to the direct gaze compared to the averted gaze or the closed eyes. Because anxiety and fear are related to heightened autonomic activation (Kreibig, 2010), we expected that this pronounced sympathetic activation to the direct gaze would be more salient in the SAD group than in the control group. Secondly, we hypothesized that participants in the SAD group would show more avoidance-related brain activity and choose shorter viewing times when observing a face with a direct gaze compared to the participants in the control group.

To supplement the physiological data in Studies Ia, II, and III, we also measured situational public self-awareness using the Situational Self-Awareness Scale (SASS) (Govern & Marsch, 2001). Govern and Marsch (2001) have suggested that situational self-awareness consists of three factors: private self-awareness, public self-awareness, and awareness of surroundings. In this work, we concentrate on public self-awareness, which refers to the tendency to attend to aspects of the self that are matters of public display (e.g., overt behavior, mannerisms, and expressions) (Buss, 1980; Govern & Marsch, 2001). Public self-awareness is also associated with the feeling of being evaluated by another person (Buss, 1980), a feeling that naturally occurs when being looked at by another person. In Study III, we also measured self-assessed affective valence (pleasantness) and arousal using the Self-Assessment Manikin (SAM) (Bradley & Lang, 1994).

3 METHODS AND RESULTS

3.1 General methodology

In all studies, a live person (a model) was used as a stimulus. The model bore a neutral expression and either gazed straight ahead or gazed 30° to the left or the right. In Study III, the model was also presented with closed eyes. The model's face was presented through a voltage-sensitive LC shutter (NSG UMU Products Co., Ltd.) attached to a black panel positioned between the model and the participant. A female experimenter acted as the stimulus in Study Ia, a female (for half of the participants) and a male (for the half) experimenter acted as stimuli in Studies Ib and II, and three females, naïve to the purpose of the experiment, served as models in Study III. All models had some interaction with the participants prior to the experiment and were trained to act similarly towards the participants. In all experiments, participants were instructed that their task was simply to watch the model while the LC window was open.

For all studies, ethical approval was obtained from the Tampere Area Ethical Review Board (Studies I-II) or the Ethical Committee of Pirkanmaa Hospital District (Study III). Participant consent was obtained according to the Declaration of Helsinki.

3.2 Methodology for Studies I - II

In each study, 24-26 healthy adults with normal or corrected-to-normal vision were recruited as participants. The three studies (Ia, Ib, and II) had different sets of participants. In Study Ia, the participants were 26 right-handed undergraduate students (14 females, 12 males). Five participants (3 females, 2 males) were excluded from the analysis due to the fact that they did not believe in the half-silvered mirror deceit or because they admitted, after the half-silvered mirror condition, that they had forgotten that the model could not see them. Additionally, one female and one male participant were excluded from the ERP analysis and one male was excluded from the electrocardiogram analysis due to technical error. Thus, the final data sample consisted of 21 participants (11 females, 10 males) for the SCR and the questionnaire, 19 participants (10 females, 9 males) for the ERP, and 20 participants (11 females, 9 males) for the electrocardiogram (ECG). In Study Ib, the participants were 24 undergraduate students (13 females, 11 males, mean age of 27.0 years, range of 21–53 years). In Study II, the participants were 25 right-handed undergraduate students (15 females, 10 males) with normal hearing. Seven female participants were excluded from the ECG and SCR analyses due to an error in the script of the computer program causing data not to be recorded. Additionally, two male participants and three female participants were excluded from the P3 analysis due to excessive artifacts. Thus, the final data sample consisted of 25 participants for the questionnaire, 18 participants (8 females, 10 males) for the SCR and ECG, and 20 participants (12 females, 8 males) for the ERP.

In the three experiments, we manipulated participants' ability to see the model (or the model's eyes) and/or the participants' belief of whether the model could see the participant. To these ends, we used either a deception procedure (Studies Ia and II) or different kinds of sunglasses worn by the model (Study Ib). By using transparent and opaque sheets in front of the LC window and convincing the participants (using deception) that these sheets were indeed transparent or opaque depending on which side they were looked through, we were able to create four different viewing situations: 1) the participant saw the model and believed that the model also saw him/her (referred to as "seeing and being seen"), 2) the participant saw the model and believed that the model could not see him/her (referred to as "seeing but not being seen"), 3) the participant did not see the model and believed that the model could see him/her (referred to as "not seeing but being seen"), and 4) the participant did not see the model and believed that the model could not see him/her (referred to as "not seeing and not being seen"). Study Ia included viewing situations 1) and 2), and Study II included viewing situations 1), 3), and 4). In study II, a buzzing sound indicated the onset of the viewing situation. To control for the suspicion of deceit, the participants were asked about their experienced differences during the different stimulus presentation conditions after the experiments. During the final debriefing, the deceits were unveiled and the participants were asked directly if they had any doubts about the model either seeing or not seeing them during the different viewing situations. Participants were excluded from the analysis if any clear doubts of deceit were expressed on any of these occasions. The model was interviewed after each experiment to control for participants' unusual gazing behavior (e.g. not making eye contact).

In Study Ib, we manipulated the visibility of the model's eyes to see whether observing or not observing the other person's eyes is crucial for bodily responses to eye contact. To this end, the model used three different sunglasses: 1) with no lenses, thus enabling the model to see the participant and have his/her eyes visible, 2) with normal dark lenses, thus enabling the model to see the participant and not have his/her eyes visible, and 3) with blocked dark lenses, preventing the model from seeing the participant and not having his/her eyes visible. The participant was always aware of which lenses were used by the model.

We measured skin conductance in all experiments. Additionally, in experiments Ia and II, we measured HR, EEG, and self-assessed public self-awareness. We analyzed frontal P3a responses from EEGs 200 and 450 ms after the beginning of the stimulus presentation.

SCR data were collected using two electrodes attached to the palmar surface of the medial phalanxes of the index and middle fingers of the participant's left hand. SCR was defined as the maximum amplitude change from the baseline level (at the stimulus onset) during a 4-second time period starting 1 second after stimulus onset. The data were averaged for each condition and gaze direction for each participant, including those with maximum amplitudes below 0.01 µMho (i.e. zero responses). This calculation gives us the *magnitude* of the SCR, which is a measure that combines response size and response frequency (cf., Dawson, Schell, & Filion, 2000).

For HR measurements, two electrodes (Ag/AgCl) were placed on both arms. The ECG data were analyzed offline using an in-house (Matlab-based) algorithm to measure the time intervals between two successive R-waves (inter-beat interval, IBI). For a period between 5 seconds pre-stimulus and 10 seconds post-stimulus within each trial, the IBIs were quantified and assigned to 1-second intervals. Lastly, IBIs were converted to beats per minute (bpm) and averaged across trials within each condition. A baseline was defined as the average of the IBIs during the 5-second pre-stimulus period. The analyses were performed with HR-change scores, which were calculated by subtracting the bpm of each post-stimulus 1-second interval from the baseline. Negative change score values indicate HR deceleration, while positive values indicate HR acceleration during stimulus viewing.

Continuous EEGs were recorded from 64 sites using actiCAP active electrodes, and the signal was amplified using a quickAmp amplifier (Brain Products GmbH, Munich, Germany). An average reference was used. In order to study the ERP responses, the signal was segmented into 600-ms-long epochs starting 100 ms before the stimulus onset and computed for each condition and gaze direction. The baseline was computed from the 100-ms pre-stimulus period. For the P3a response, we analyzed right and left anterior frontal and frontal pole regions averaged over electrodes AF3, AF7 and Fp1, and AF4, AF8 and Fp2, and measured the mean amplitude between 200 and 450 ms post-stimulus for each participant in each condition.

3.3 Results of studies I - II

3.3.1 Skin conductance responses

Figure 1 shows the mean SCR values for each gaze direction when participants saw the model and believed that they were either seen or not seen by the model (Study Ia). Overall, the responses were significantly larger when the participants believed that the model could see them through the LC window. When the participants believed that the model could see them, the responses to direct gaze were significantly larger than those to averted gaze. This difference was not observed when the participants believed that they were not seen by the model.

Figure 2 shows mean SCRs in viewing situations 1), 3), and 4) (Study II). All of the responses were measured for direct gaze. The responses were significantly higher when the participant and the model could see each other compared to when only the model could see the participant or when neither could see each other. No significant differences were found between when the model could see and when he or she could not see the participants when the participant could not see the model.

The mean SCR values for the condition during which the model was using different sunglasses are shown in Figure 3 (Study Ib). When the participants knew that they were being seen by the model, the responses to direct gaze were significantly larger compared to the responses to averted gaze, regardless of whether the eyes were visible or not (the no lenses and normal sunglasses blocks). When the participants knew that the model could not see through the lenses, the difference in responses between direct and averted gazes was not observed. Additionally, the responses to direct gaze in the two blocks where the participants knew that the model was able to see them were significantly larger compared to those to direct gaze in the third block, where the participants knew that the model was not able to see.

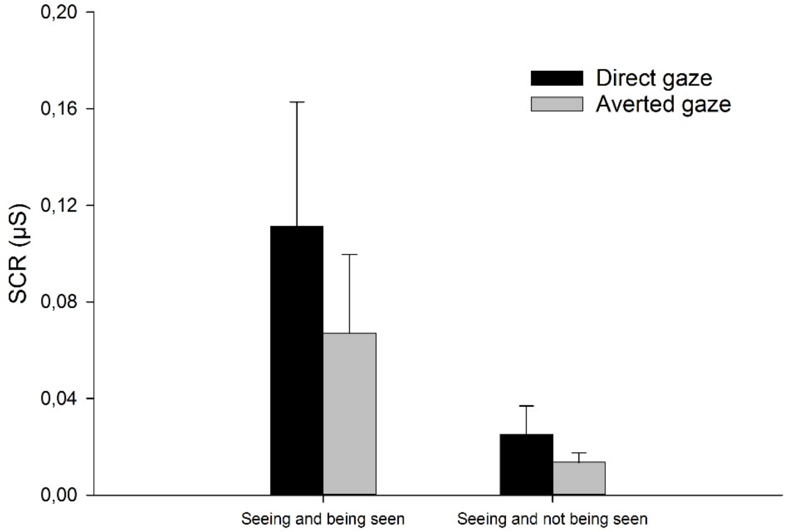

Figure 1. Skin conductance responses (mean + standard error of the mean [s.e.m.]) to direct and averted gazes in the two presentation conditions.

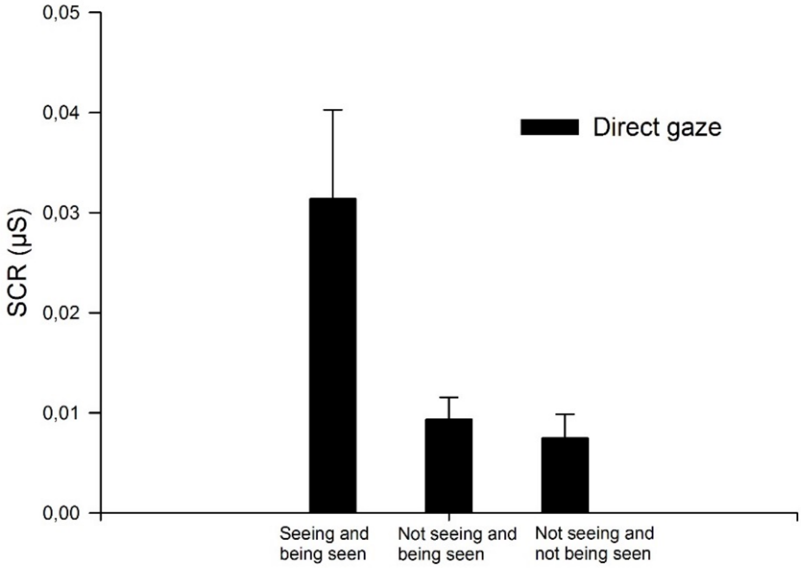

Figure 2. Skin conductance responses (mean + s.e.m.) for the three different viewing situations.

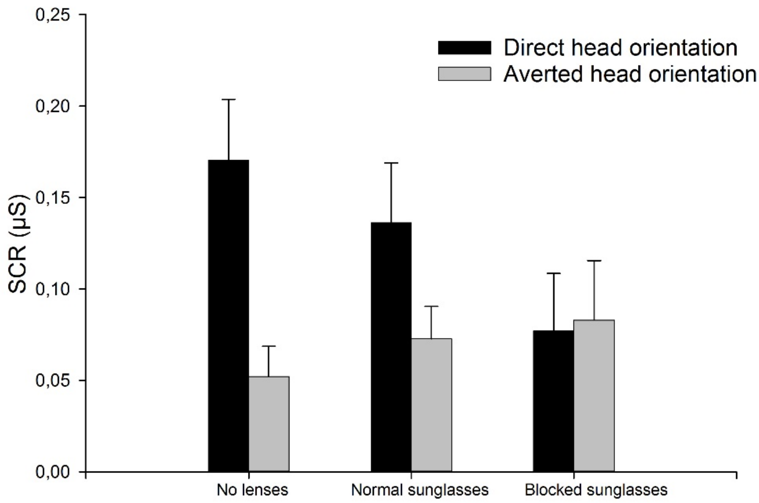

Figure 3. Skin conductance responses (mean + s.e.m.) to direct and averted gaze in the three presentation conditions. In the "no lenses" condition, participants saw a model wearing sunglasses frames without lenses (eyes visible). In the "normal lenses" condition, the model was wearing normal sunglasses (eyes not visible, but the model saw through the lenses). In the "blocked lenses" condition, the model was wearing sunglasses with the lenses blocked from the inside (eyes not visible, the model could not see through the lenses).

The mean SCR values for the condition during which the model was using different sunglasses are shown in Figure 3 (Study Ib). When the participants knew that they were being seen by the model, the responses to direct gaze were significantly larger compared to the responses to averted gaze, regardless of whether the eyes were visible or not (the no lenses and normal sunglasses blocks). When the participants knew that the model could not see through the lenses, the difference in responses between direct and averted gazes was not observed. Additionally, the responses to direct gaze in the two blocks where the participants knew that the model was able to see them were significantly larger compared to those to direct gaze in the third block, where the participants knew that the model was not able to see.

3.3.2 Heart rate

The HR-change scores for the viewing situations "seeing and being seen" and "seeing but not being seen" are presented in Figure 4 (Study Ia). The results indicate the presence of an HR deceleration response to all situations and gaze directions. However, the deceleration was more prominent for direct gaze than averted gaze only when the participants believed that they were seen by the model. The effect was not present when the participants believed that the model's visibility was blocked.

HR deceleration responses for the viewing situations "seeing and being seen", "not seeing but being seen", and "not seeing and not being seen" are shown in Figure 5 (Study II). The measurements were made only for direct gaze. The HR deceleration was more prominent when the participants and the model were able to see each other than when the model could see the participant or when neither could see each other. There was no significant difference in HR deceleration between when the model could see and when he/she could not see when the participant was not able to see the model.

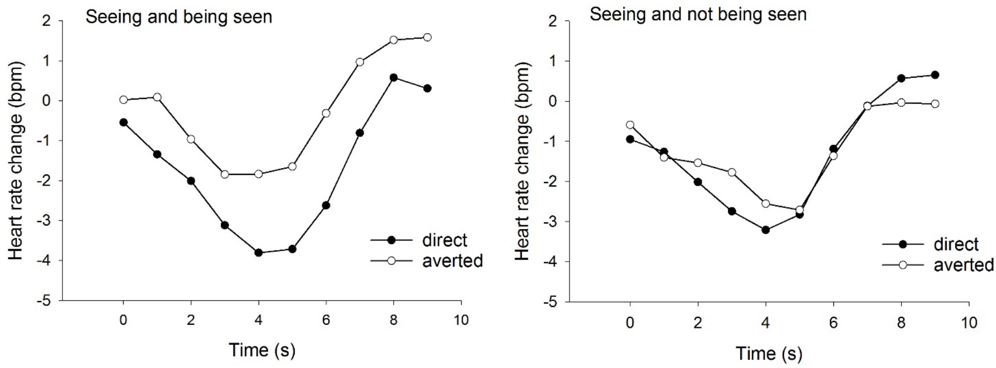

Figure 4. Heart rate changes in relation to direct and averted gaze in two viewing situations.

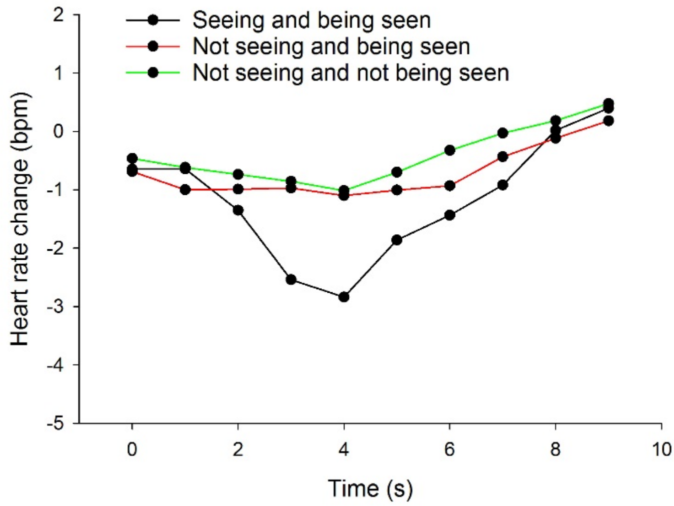

Figure 5. Heart rate changes in the three different viewing situations for direct gaze.

3.3.3 Event-related potential response P3a

The grand averaged P3a ERPs are presented in Figure 6 for each gaze direction when participants saw the model and believed that they were either seen or not seen by the model (Study Ia). In the frontal P3a response (mean amplitude between 200 and 450 ms post-stimulus), a more positive response was observed for direct versus averted gaze. Importantly, this difference was present only when the participants believed that they were being seen by the model and not when they believed that the model's vision was blocked.

In Study II, which included the viewing situations "seeing and being seen", "not seeing but being seen", and "not seeing and not being seen", there was an expected modulation of the ERP responses whereby the presence of the visual stimulus induced a prominent negative shift in the waveform for the condition where the participant was able to see the model. However, there were no significant differences in the P3a waveform between when the model could see the participant and when he/she could not see the participant when the participant was not able to see the model. The P3a ERP responses are shown in Figure 7. The measurements were only made for direct gaze.

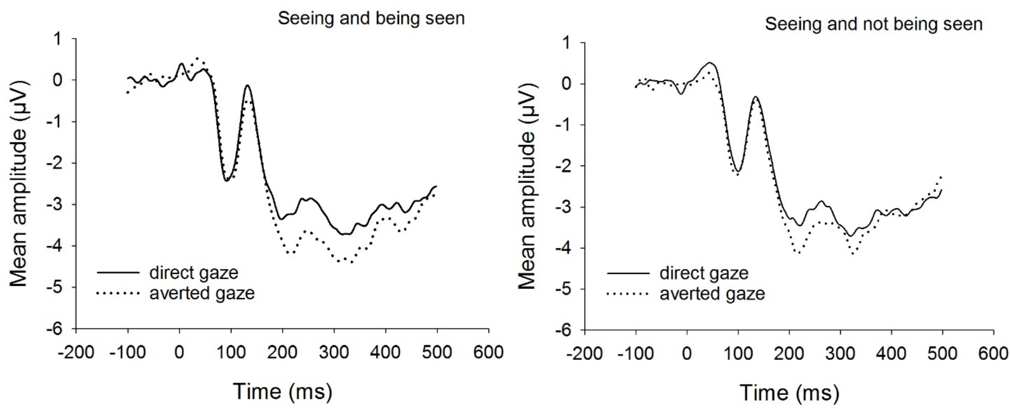

Figure 6. Grand averaged frontal P3a waveforms to direct and averted gaze in two presentation conditions. Waveforms are averaged from the left and right frontal electrode sites. The time frame of interest is (200 ms to 450 ms). P3a response takes place simultaneously with a larger negative response, which is why the overall polarity is negative.

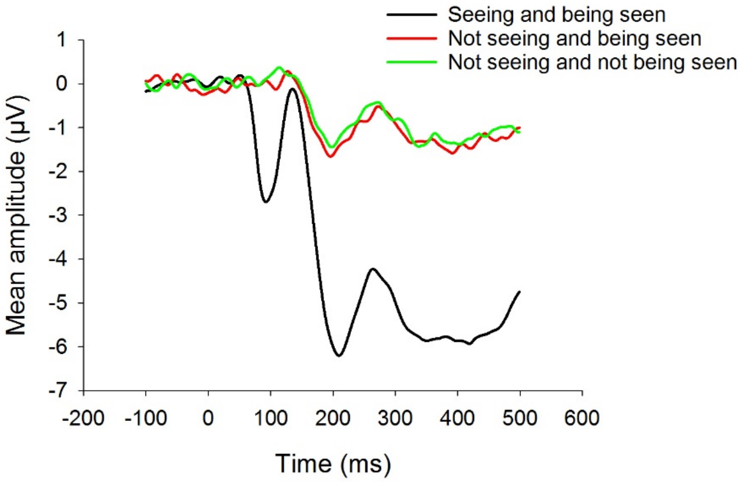

Figure 7. Mean waveforms from the frontal electrode sites in the three different experimental conditions for direct gaze. The presented waveforms are averaged over the left and right hemispheres. The timeframe of the P3a response is 200–450 ms.

3.3.4 Public self-awareness

Public self-awareness ratings for Studies Ia and II are shown in Table 1. All comparisons were made between viewing situations and not between gaze directions. Stronger self-assessed public self-awareness was observed when the participants believed that they were being seen versus when they believed that they were not being seen by the model (Study Ia). In Study II, the situational public self-awareness was significantly greater both when the participant and the model could see each other and when the participant did not see the model, but believed that the model could see him/her compared to when neither could see each other. Public self-awareness did not differ significantly between when the participant and the model could see each other and when the participant did not see the model, but believed that the model could see him/her. Thus, self-evaluated public self-awareness was enhanced independent of whether the participant saw the model, as long as he/she believed themselves to be observed by the model.

Table 1. Self-rated public SSAS scores for all viewing situations in Studies Ia and II. Scale range of scores is 1-7.

Viewing situation	Public self-awareness	
	M	*SD*
Seeing and being seen (Study Ia)	2.73	1.47
Seeing but not being seen (Study Ia)	2.15	1.12
Seeing and being seen (Study II)	3.04	1.61
Not seeing but being seen (Study II)	2.81	1.58
Not seeing and not being seen (Study II)	2.21	1.37

3.4 Methodology for Study III

The participants were seventeen adolescents with SAD (mean age of 15.2 years, standard deviation [std] of 1.52, range of 13-17) and seventeen age- and sex-matched controls (mean age of 15.3 years, std of 1.53, range of 13-17). Adolescents with SAD were recruited from the Department of Adolescent Psychiatry, Tampere University Hospital. Participants were included in the clinical group if their primary reason for referral was social anxiety and they fulfilled Diagnostic and Statistical Manual of Mental Disorders IV criteria for SAD. The participants did not have neurological or medical diseases and were not taking regular medication. The control participants were recruited from local upper comprehensive and high schools, screened with the Social Phobia Inventory (SPIN) (Connor et al., 2000), and invited to an interview with an adolescent psychiatrist if the SPIN score was 0-9, which represent low levels of social anxiety. All of the clinical participants had SPIN scores higher than 20. Only those without SAD, and those without any other anxiety/affective or other Axis I disorders were included in the control group.

The experiment consisted of a computer-controlled viewing-time situation, and a self-controlled viewing-time situation, where the participants were instructed to use a computer mouse for opening and closing the LC window themselves. As the participants viewed the model, skin conductance and EEG were measured. In the self-controlled viewing-time situation, the viewing times were recorded. After the physiological measurements were obtained, the participants were asked to fill self-assessment forms. Arousal and affective states were measured when the participants observed faces with direct gazes, averted gazes, and closed eyes. Situational public self-awareness was measured when the participants observed faces with direct and averted gazes.

SCR data were collected and analyzed in a similar manner as in Studies I and II.

Continuous EEG was recorded from eight electrode sites (F3, F4, F7, F8, C3, C4, P3, and P4) positioned according to the 10-20 system. The signal was referenced to mathematically linked ears. Horizontal and vertical eye movements were recorded from the sites beside the outer canthi of each eye and above and below the left eye. The EEG-signal was segmented into nine 1,024 ms-long epochs with a 50% overlap between adjacent epochs starting from stimulus onset. The epochs were manually checked for artifacts. Spectral power was calculated for each artifact-free epoch using Fast Fourier Transform (FFT). The obtained power spectra were averaged over all artifact-free epochs within each trial and over separate trials within each experimental condition (direct gaze, averted gaze, and eyes closed). Power density values ($\mu V^2/Hz$) within the alpha-band (8-13) were calculated. Lastly, alpha-asymmetry [Ln (PowerDensity F4) – Ln (PowerDensity F3)] scores were calculated.

The self-controlled viewing times were recorded in the second experimental condition. The viewing-time data were averaged in both gaze conditions for each participant.

3.5 Results of Study III

3.5.1 Skin conductance responses

In the computer-controlled presentations, significantly larger SCRs for direct versus averted gaze were observed. However, there were no significant differences between the clinical and control groups. In the self-controlled presentations, the direct gaze induced significantly larger SCRs in the clinical group, but not in the control group. Mean SCRs for each gaze direction and for both groups are presented in Figures 8a (computer-controlled presentations), and 8b (self-controlled presentations).

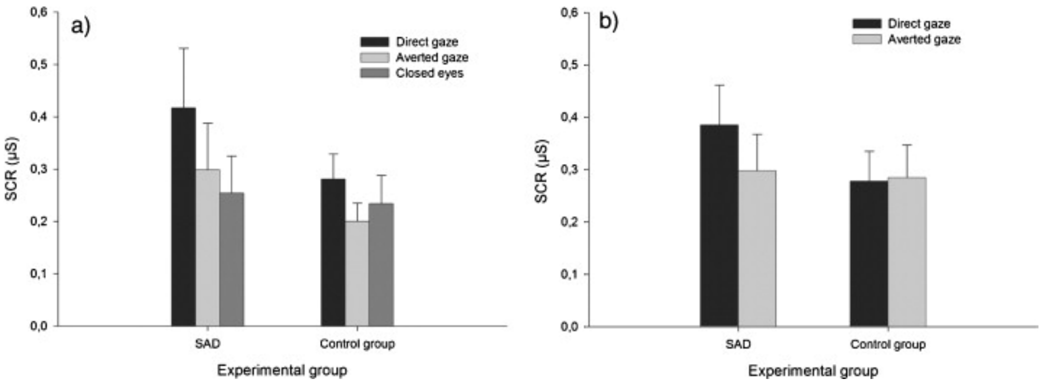

Figure 8. Mean skin conductance responses to direct gaze, averted gaze, and closed eyes (a) in the computer-controlled viewing-time condition and (b) in the self-controlled viewing-time condition.

3.5.2 Frontal alpha-asymmetry

Figure 9 presents the mean frontal alpha-asymmetry scores for both experimental groups in the computer-controlled stimulus presentation condition. The result was only marginally significant, but it suggested that alpha-asymmetry scores when seeing a face with a direct gaze were more positive in the control group than in the clinical group.

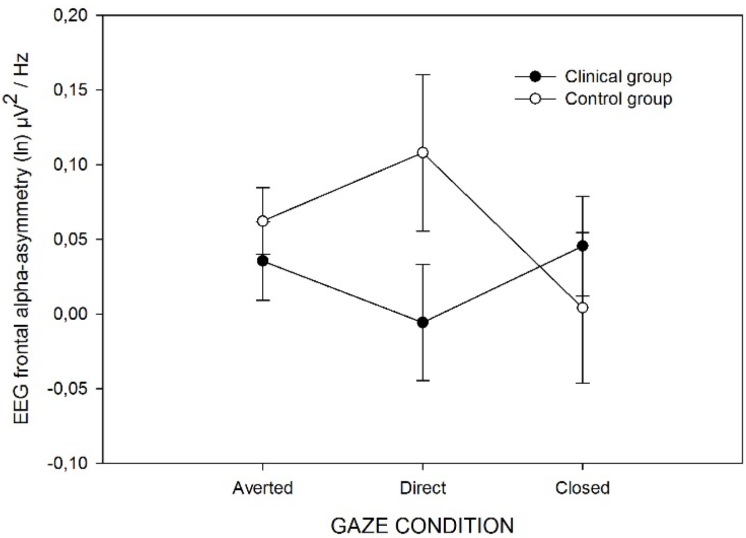

Figure 9. Mean frontal alpha-asymmetry scores to direct gaze, averted gaze, and closed eyes. A positive value indicates stronger relative left-sided frontal brain activity associated with approach-motivation and a negative value indicates stronger relative right-sided frontal brain activity associated with avoidance–motivation.

3.5.3 Viewing times

Figure 10 shows mean viewing times for the self-controlled presentation block for direct and averted gazes in both experimental groups. The clinical participants chose significantly shorter viewing times compared to the control participants when the model had a direct gaze. When the model had an averted gaze, no differences in viewing times were observed.

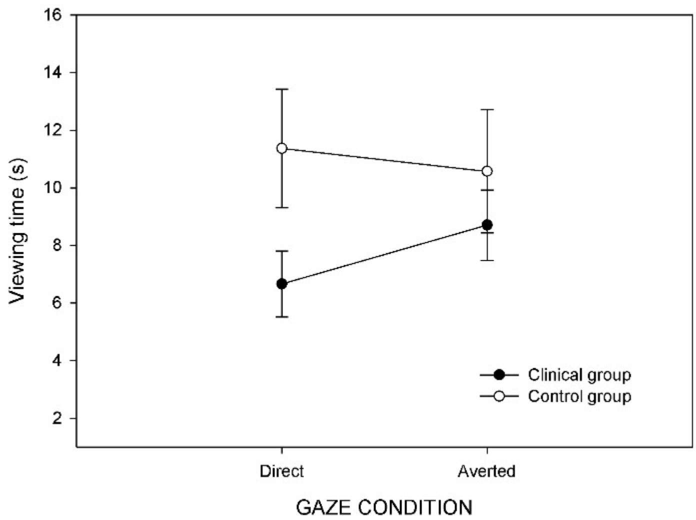

Figure 10. Mean preferred viewing times to direct gaze and averted gaze facial stimuli in the self-controlled viewing time condition.

3.5.4 Self-assessments

The subjective ratings of arousal and valence and situational public self-awareness scores are shown in Table 2. Clinical participants assessed their arousal as significantly higher compared to the controls for direct gaze, but not for averted gaze or closed eyes. Clinical participants also provided significantly lower pleasantness ratings than controls for direct gaze, but not for other gaze conditions. Importantly, participants in the control group evaluated direct gaze as mildly pleasant (M = 5.43), whereas the participants with SAD evaluated direct gaze as unpleasant (M = 3.19). The self-assessed public self-awareness was significantly higher in response to direct vs. averted gaze and was higher overall in the clinical group than in controls.

Table 2. Arousal, valence, and self-rated public SSAS scores for the clinical and control groups in Study III. Arousal and valence scores range from 1 to 9 and SSAS scores range from 1 to 7.

	Clinical group			Control group		
	Direct gaze	Averted gaze	Closed eyes	Direct gaze	Averted gaze	Closed eyes
Arousal	4.63 (2.03)	3.12 (1.69)	2.38 (1.20)	3.00 (1.59)	2.71 (1.45)	1.75 (1.13)
Valence	3.19 (1.94)	4.5 (1.67)	5.94 (1.43)	5.43 (1.59)	5.44 (1.31)	6.06 (1.34)
Public SSAS	4.74 (1.71)	3.68 (1.30)	-	2.90 (1.71)	2.35 (1.40)	-

4 DISCUSSION

The present studies investigated physiological, behavioral, and self-assessed responses to eye contact. Previous research has mostly neglected the influences of mental attributions, which naturally differ in different social contexts. In Study Ia, the participants were shown a model making eye contact or one gazing aside, and were either able or not able to see the participant. The autonomic, brain, and self-assessed responses of participants were enhanced when making eye contact with the model compared to when they saw the model gazing aside, but only when the participant believed that the other person was able to see him/her. This finding indicates that the knowledge of being observed by another person is a key element in the induction of bodily and self-assessed responses to eye contact. In Study Ib, we investigated whether seeing the eyes is necessary for the effects caused by eye contact. There are suggestions that the effects of eye contact are mediated by fast-operating subcortical structures (Senju & Johnson, 2009). Hiding the eyes, thus, potentially diminishes or blocks the bodily responses associated with eye contact. Our results, however, indicate that seeing the eyes is not necessary for the enhancement of autonomic responses to seeing a person with a direct versus an averted posture. Study Ib demonstrated that the key element for bodily responses to eye contact is, indeed, the knowledge of being seen by another person, even if the other person's eyes are not visible. To further examine this phenomenon, in Study II, bodily responses were measured when participants believed they were being seen by another person, but were prevented from seeing, not only the eyes of this person, but the whole person. The responses were compared between a natural eye contact situation and a situation of a private sitting when another person was present in a room (but unable to see the participant). The findings indicated that the belief of being seen by another person does not by itself induce heightened bodily responses when no visual cues of this other person are present, but does have an effect on self-assessed public self-awareness. Finally, in Study III, we investigated the effects of eye contact on adolescents with SAD and healthy controls. The findings revealed a consistent pattern of results showing larger autonomic and altered brain, behavioral, and self-assessed responses to eye contact in adolescents with SAD compared to healthy controls.

4.1 Autonomic responses to eye contact: to see and to be seen

Studies I-II revealed an intriguing interplay between gaze direction and mental attributions affecting physiological and self-assessed responses. The purpose of the sympathetic nervous system is to prepare the body for action. Traditionally, it is seen as the "fight or flight" system and is thought to not have much social function (Cannon, 1928). According to the polyvagal theory, autonomic regulation related to changing social situations takes place parasympathetically via the VVC, while sympathetic modulation is recruited only during danger or threat (Porges, 2001). Research has shown that sympathetic activity measured by SCR is associated not only with danger or threat, but with various psychological processes associated with attention, emotion, and motivation (Figner & Murphy, 2011). The results of the present studies show that there is a larger sympathetic activation, as measured by SCR, to eye contact versus averted eyes, but only if the eye contact is combined with the knowledge of being seen by another person (Study Ia). The larger sympathetic activity persists even if the other person's eyes are not visible (Study Ib). However, if the other person is completely out of sight, the sympathetic activity ceases (in the eye contact versus the not seeing but being seen condition) (Study II). These results can be interpreted in terms of a potential for interaction. We observed heightened sympathetic activation in situations in which two people were looking at each other and seeing each other. In those situations, the subjects were able to influence each other with their own behavior, and were at the same time potentially influenced by the other person's behavior. Whenever this possibility of two-way interaction was broken, either knowledge of the other person not seeing the observer or by blocking the observer's visibility of the other person, were no longer observed a heightened sympathetic activation for direct versus averted gaze (Studies Ia and Ib) or for having one-way versus no visibility (Study II). This observation calls for a broadening of the traditional theories regarding the functions of the sympathetic nervous system. As stated before, the purpose of the sympathetic nervous system is to prepare the body for action, and the present results suggest that the sympathetic system prepares the body not only for unelaborated actions, such as fighting or fleeing, but also for more sophisticated actions, such as interaction.

The HR and P3a results provide further information regarding the bodily and psychological processes associated with eye contact. They are both closely related to attentional processes and reflect the intensities of the attention-orienting (HR) and initial target stimulus processing (P3a) functions. These responses indicated a similar interplay between eye contact and mental attributions affecting bodily responses to SCR. The responses were larger in eye contact versus no eye contact situations, but only when the participant believed that he/she was being seen by the watched person (Studies Ia and II). If the participant believed that the other person could not see him/her (Study I), or if the participant's visibility was blocked (Study II), HR and P3a responses did not differ in response to direct versus averted gaze (Study Ia) or to one-way versus no visibility (Study II). These measures were not included in Study Ib, so we do not know if the HR deceleration response and P3a are sensitive to whether the pair of eyes is visible or not. Combined with the SCR results, the physiological results suggest that the regulation of the autonomic nervous system and the attentional state in social encounters is considerably moderated by the individual's beliefs and interpretations of the situation. Specifically, these results demonstrate that when sensory information and the individual's interpretation both indicate a possibility for interaction, the autonomic system and attentional mechanisms prepare the individual to meet the demands of a social encounter.

In their review article, Frith and Frith (2010) discuss two different types of social signals: involuntary and deliberate (or ostensive). Involuntary signals are often automatic, and reading them serves the function of collecting information about the (social) environment. Involuntary signals are processed when we, for example, interpret biological motion, infer whether somebody has a mind or not, predict behavior, or imitate. Ostensive signals, on the other hand, attract attention and are used to signal the willingness to carry out, or the possibility of, two-way communication (Frith & Frith, 2010, 2012). Ostensive signals include those such as an eyebrow flash (Eibl-Eibesfeldt, 1972) or making eye contact. Ostensive signals are shown to be critical from very early ages: Senju and Csibra (2008) showed that infants follow the actions of adults only if they are preceded by the adult's ostensive signal. As involuntary signals are important for collecting information, ostensive signals are essential in communicating, participating, learning, and, ultimately, building up a culture (Frith & Frith, 2010; Csibra & Gergely, 2006). This viewpoint, combined with the present results, inspires the suggestion that (ostensive) social signals are context-dependent, such that the meaning given to a signal is a function of not only the signal, but also of the state of mind of the observer. An eyebrow flash, for example, is an ostensive signal only if the observer interprets it as a deliberate signal from the other person. Thus, an eyebrow flash seen in a video is not an ostensive signal from the observer's viewpoint. Autonomic and attentional mechanisms are tuned to ostensive signals and prepare the individual to act efficiently after such a signal is observed. This suggestion is also justified from an evolutionary perspective. Given the importance of social encounters for individuals and for whole populations, it is reasonable that as interactions began to be emphasized during human evolution, there evolved mechanisms that targeted attentional and cognitive resources to social events. This may have involved broadening of the functions of the sympathetic system from simple "fight or flee" behaviors to "flight or flee or socialize" behaviors. On the other hand, according to the polyvagal theory (Porges, 1998, 2001), the primary operator during communication and social interaction is the parasympathetically mediated VVC. However, our results suggest that the less elaborated sympathetic system also has an important and active role in interactive situations. It is possible that the sympathetic system is activated only when initiating interactions or when the person is in a novel interactive situation (for example in the presence of an unfamiliar person). What and how large, exactly, the role of sympathetic system is, and how the sympathetic system and the VVC complement each other in different interactive situations should be investigated in future studies.

An important result of the present studies is that the self-assessed situational public self-awareness to gaze stimuli was not modulated is a similar manner as the physiological responses by the belief of being seen. Whereas the measured physiological responses were enhanced only when there was 1) visual perception of another person with a direct gaze, and 2) the knowledge of being seen by this another person, the self-assessed situational public self-awareness was enhanced in all situations where there was a knowledge of being seen by another person (with a direct gaze) regardless of whether that person was visible or not. This is an important observation, given that Studies Ia and Ib alone would lead to a plausible hypothesis stating that the effects of eye contact on measured physiological responses are mediated by public self-awareness. This hypothesis is also supported by cognitive theories of self-regulation, which state that self-regulatory systems, such as self-awareness, mediate the effects of most external influences (Bandura, 1991). The results of Study II suggest, on the other hand, that public self-awareness and physiological responses are parts of a more complex system. Moreover, a correlational analysis does not offer strong evidence of the close relationship between public self-awareness and physiological responses. For example, for the direct gaze condition, the correlation between SCR and public self-awareness was only moderate for the seeing and being seen condition in Study Ia ($r = 356$, $p = .081$) was weak for the other conditions in Studies Ia and II (ps > 0.2). Thus, public self-awareness may be a mediator of the measured physiological responses (we did not observe heightened physiological responses without heightened public self-awareness), but it is not a strong enough mediator to induce bodily responses without the involvement of other mechanisms (we observed heightened public self-awareness without heightened physiological responses). These other mechanisms may be related to automatic processes taking place when observing an eye-contact stimulus (Senju & Johnson, 2009) and/or more complex sets of regulatory processes related to behavioral adjustment in social environments (Bandura, 1991). In future studies, it would be important to look more closely at how different self-regulatory processes affect bodily responses during eye contact situations with another real person, possibly by interacting with automatic visual processes.

Audience effects have been studied for a long time as a part of extensive social facilitation research starting in the late 19th century. There is plenty of evidence on how an audience or the presence of another person can affect behavior and task performance (for reviews, see Zajonc, 1965; Guerin, 1985; Aiello, Douthitt, 2001). Interestingly, it has been demonstrated that only the knowledge of another person looking, without seeing that person, can affect behavior (Cohen & Davis, 1973; Stanton & Barnes-Farrell, 1996), and that the medial prefrontal cortex, closely associated with theory of mind-processing and eye contact, is more strongly engaged when there is a belief of being seen compared to when there is a belief of not being seen by another person in a situation where the other person is not visible (Somerville, Jones, Ruberry, Dyke, Glover, & Casey, 2013). On the other hand, there is evidence showing that simple visual cues from another person looking have effects on behavior, even if it is clear that there is nobody really looking. For example, posters with eyes induce people to pay more for their coffee (Bateson, Nettle, & Roberts, 2006) and displaying eye-stimuli in the players' environment increased the probability of donating in a dictator game (Nettle, Harper, Kidson, Stone, Penton-Voak, Bateson, 2013). These studies suggest that only seeing visual cues from another person looking, or only having a belief of another person looking, can have effects on behavior, performance, self-assessed measures, and neural responses. However, the present studies indicate that when these two components, looking and being looked at, are considered together, the effects may be remarkably stronger than when only one of them is present.

One possible weakness of Studies I and II is that they used a within-subjects design. Thus, when manipulating the state of the belief - whether or not the subject is being seen by another person - the same participants took part in all conditions within one study. There is a possibility that this resulted in creating a contrast between the different conditions, augmenting the manipulation effect, and increasing the probability of observing effects in the measured responses. The same possibility is also present in previous studies observing differences in physiological responses between when a subject sees a real person and when he or she sees a picture or a dummy (Hietanen et al., 2008; Pönkänen, Peltola, & Hietanen, 2011; Pönkänen, Alhoniemi, Leppänen, & Hietanen, 2011; Pönkänen et al. 2008). One important open question for future studies is to examine whether within-subjects designs have an amplifying effect on the observed differences.

One can question whether our manipulations in Studies I and II really worked as intended, and whether the participants were convinced that they were either seen or not seen by the model during the different experimental conditions. Participants were interviewed after the experiments and not a single participant expressed strong doubts regarding the deceit before being informed of the experiment in Studies Ib and II. In Study Ia, five participants were excluded from the analysis because they did not believe in the deceit or because they admitted, after the deceit condition, that they had forgotten that the model could not see them. In Study II, there were five participants expressing doubts of deceit after the deception was unveiled. We re-analyzed the data leaving out these five participants in Study II, and still there were no signs of differential physiological responses to being seen versus not being seen when the model was not visible. Most importantly, the public self-awareness rating results strongly indicate that our experimental manipulation worked as intended. It is difficult to account for the stronger public self-awareness in conditions when the participants believed that they were being seen versus those when the participants believed that they were not being seen by the model in Study II if our manipulations did not work properly.

Another possible weakness of the present studies is that the behavior of the models was not assessed in any systematic way. There is a possibility that the models may have discreetly and unconsciously behaved slightly differently between conditions or between participants. However, all the models were trained carefully and in study III (where this issue is perhaps most critical), the models did not know the purpose of the experiment. There is no reason to believe that the behavior of the models was different between conditions, but in future studies it would be reasonable to film the models and have their behavior assessed by naïve judges.

The present results are important from the perspective of interaction. De Jaegher et al. (2010) proposed that interaction includes at least two agents co-regulating and mutually affecting each other while preserving their individual autonomies. In fact, Jaegher and colleagues explicitly suggest that belief in another person's presence is not enough to constitute genuine social interaction. This is in accordance with the results in the Study II, where only belief in another person looking without visual cues of that person was not enough to elicit the bodily responses observed in natural eye contact situations. In a recent seminal review, Schilbach et al. (2013) use the term "spectatorial gap" to describe a situation where a person is merely observing his/her surroundings without the possibility of interacting with it. They suggest that when the possibility of interaction and/or emotional engagement is prevented, social cognition may be fundamentally different compared to when there is a natural encounter with another person. A very recent experiment demonstrates this. It was shown that whereas a direct gaze seen in a picture potentially holds attention (see also, Senju & Hasegawa, 2005), a direct gaze of a live person enhances the disengagement of attention (Hietanen, Myllyneva, Helminen, & Lyyra, under review), thus demonstrating that eye contact effects can be qualitatively different in interactive versus non-interactive situations. The present results are well in line with the above considerations and provide empirical evidence for them. The results of our studies show that closing or not closing this spectatorial gap can, indeed, have a major effect on attention and affective arousal-related autonomic and brain responses.

One can visualize the (nonverbal) interactive situation using a simple model (Figure 11). In an interactive situation, one sees the other (blue arrows), and at the same time is being seen by the other (red arrows). Without the experience of looking at the other individual, one is essentially locked in an observation room with a one-way mirror without any chance to be impacted by the other individual's behavior. Without the experience of being looked at by another individual, one may merely be a passive observer, comparable to a television viewer, without the possibility to impact the other individual. When both these elements are present, the situation is truly interactive, ostensive signaling is possible, and the interactor reacts (with bodily and attention-related responses) appropriately to social cues. This simple model is the most parsimonious explanation of the results from our previous studies and the present research.

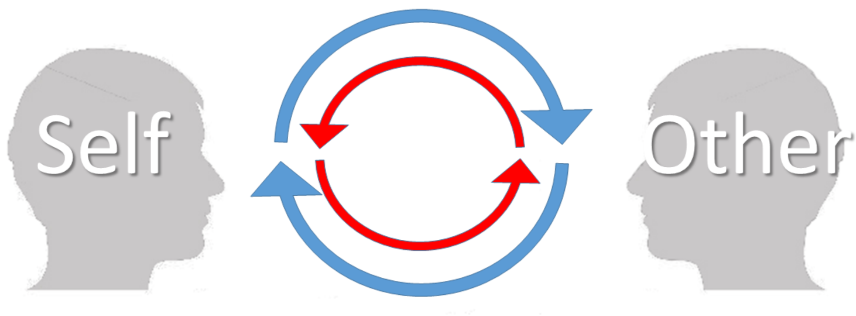

Figure 11. An illustration visualizing (nonverbal) interaction between two persons, the "self" and the "other". Blue arrows depict an individual's experience of seeing the other person. Red arrows depict an individual's concomitant experience of being seen by the other person. If the self is not able to see the other (as in Study II), or if the other is not able to see the self (as in Study Ia), the upper or lower half of this "circle of interaction," respectively, breaks down, preventing mutual (visual) interaction. This model can also be applied to interactions involving other sensory modalities.

During the past decade, there has been active conversation regarding the importance of using real social stimuli and real social situations in social neuroscience and social cognition research (Hari & Kujala, 2009; Hietanen et al., 2008; Risko et al., 2012; Schilbach et al., 2013; Teufel, et al., 2012). Many novel methods have been developed to overcome the difficulties in researching social phenomena during true interactions (Ho, Foulsam, & Kingstone, 2015; Konvalinka & Roepstorff, 2012; Teufel et al., 2009; Wilms, Schilbach, Pfeiffer, Bente, Fink, & Vogeley, 2010). Our method of using an LC window between two people and manipulating the participant's mental state while recording physiological responses offers one functional solution for creating experiments with a second-person approach. One important advantage of our method, compared to live video connection experiments, for example, is that using our method, there is a real (stimulus) person present. If a "true" interaction situation is implemented via a computer, it is probable that some effects related to the presence of another person (for a review, see Guerin, 1986) are attenuated or lacking altogether. The present results suggest that the potential for genuine, mutual interaction, with both interactors really present in the situation, can be a pivotal factor in modulating arousal and attention-related responses.

In future studies it would be important to explore which types of visual information may be enough (e.g., parts of the body or a silhouette) to elicit physiological responses similar to those observed when seeing the other person completely, and whether information via sensory modalities other than vision could be used to establish a similar mutual social contact resulting in enhanced physiological responses. It would also be important to study possible effects of sex, status, or personality on bodily responses in eye contact situations. Knowledge regarding these issues would be interesting not only from the perspective of social perception, but also as relevant to social media and video communication technology.

4.2 Physiological and self-assessed responses to eye contact in social anxiety disorder

In Study III, we investigated whether eye contact is physiologically arousing and motivationally aversive for adolescents with SAD and healthy controls. Social anxiety is associated with feelings of uneasiness when an individual interacts with others and anticipates the possibility of being negatively evaluated. A prominent clinical symptom of SAD is avoidance of eye contact, as well as other safety behaviors, in social situations (Greist, 1994). Studies I and II demonstrate the relevance of the knowledge of being seen by another person to responses to eye contact. Study III investigated how participants with and without SAD are affected by eye contact with a live person in a condition in which they know they are being seen by another person. We measured SCR and lateral alpha-asymmetry in EEG as indexes of behavioral approach–avoidance tendencies, as well as self-controlled viewing times of the stimulus faces. Additionally, we measured self-assessed arousal, valence, and situational public self-awareness while the subjects were looking at stimulus faces with different gaze directions. Importantly, this study was the first to examine physiological responses to eye contact in individuals with SAD using natural live stimuli (real persons with a potential of interaction).

Consistent with Studies I and II and other experiments using live persons as stimuli (Helminen et al., 2011; Hietanen et al., 2008; Nichols & Champness, 1971; Pönkänen, Peltola et al., 2011), there were larger SCRs when seeing a face with a direct gaze than when seeing a face with an averted gaze or closed eyes. Interestingly, however, when the participants controlled the viewing time themselves, this difference was only observed in adolescents with SAD. There is experimental evidence that increases in situational control can reduce people's stress and arousal (Miller, 1979). Thus, it may be the case that having the ability to control the moment of stimulus presentation lowered the arousal response in the control group, but not in the SAD group. Another possible reason for the differential responses between the experimental groups in the self-controlled viewing time condition may be associated with an active versus a passive role in the interactive situation. Our self-controlled stimulus presentation not only gave more control to the participants, but also forced them to be more active and initiate the visual interaction with the model. This may have resulted in additional stress and anxiety in the participants with SAD, specifically when perceiving a direct gaze, i.e. being looked at by another person. This is in accordance with the cognitive-behavioral model of social anxiety, which states that the primary threat in SAD is a possibility of being negatively evaluated by others because of one's own actions (Rapee & Heimberg, 1997). A third possible interpretation is also associated with the fear of negative evaluation. It is possible that this fear conflicts with the habituation process. The self-controlled viewing block was presented after the computer-controlled block for every participant. Thus, the responses to direct gaze may have been diminished in control participants due to habituation. The fear of being negatively evaluated associated with SAD may have decreased the habituation effect, which may have led to the observed differences in the responses of the subjects with SAD and controls.

Our results indicated weaker left-sided (approach-related) frontal EEG asymmetry among adolescents with SAD when viewing facial stimuli with direct gazes than among the control participants. No differences were found in frontal EEG asymmetry between the groups when seeing a face with an averted gaze or closed eyes. The effect was not strong, but the effect-size of the pairwise comparison was notable (d = 0.53). Considering that left-sided frontal EEG asymmetry has been associated with the functioning of the approach-motivational system (Davidson, 2004; Harmon-Jones, 2003; Van Honk & Schutter, 2006), the present results suggest that seeing another person with a direct gaze elicits less behavioral tendencies of approach in adolescents with SAD than in control adolescents. This fits well with the behavioral results, indicating that participants with SAD viewed a face with a direct gaze for shorter times than the controls, an effect which was not present when viewing a face with an averted gaze. Earlier studies have reported shortened viewing times to an eye area or reduced eye contact by participants with social anxiety (Daly, 1978; Farabee, Holcom, Ramsey, & Cole, 1993; Garner, Mogg, & Bradley, 2006; Moukheiber et al., 2010). Our results indicate that adolescents with SAD not only display reduced eye contact, but also choose actions that result in shorter interaction times with a person who is making eye contact with them. These EEG and behavioral observations demonstrate how subjects with SAD who are facing another person looking back at them have avoidance-related frontal EEG asymmetries at the level of brain activation, while simultaneously displaying a tendency to avoid eye contact at the behavioral level.

Adolescents with SAD assessed their subjective levels of arousal to be higher when seeing a face with a direct gaze than the controls. No differences between the groups were observed when viewing a face with an averted gaze or closed eyes. On the other hand, the self-assessed valence indicated that whereas in adolescents with SAD, increased arousal to a face with a direct gaze was accompanied by a negatively valenced affect, among the non-anxious adolescents, the increased arousal was accompanied by a positive affect. The third self-assessed measure, public self-awareness, was higher in response to direct versus averted gaze, and was higher overall in the SAD group than the control group. This is in accordance with cognitive theories of SAD (Clark & Wells, 1995; Rapee & Heimberg, 1997). In addition, similar findings have been reported in previous studies of SAD (Hope & Heimberg, 1988; George & Stopa, 2008).

Studies I and II demonstrate that a key factor modulating physiological and self-assessed responses to eye contact is not the visual perception of a direct gaze *per se,* but the belief of being seen by another person. Study III can be seen to provide evidence in support of propositions stating that a core feature of SAD is the presence of negative cognition and affect elicited by exposing oneself to other individuals' attention. This was the first reported study investigating physiological responses to eye contact in the SAD population using live stimuli. Our results demonstrate that by investigating responses to eye contact in a genuine social situation, it is possible to reveal a highly consistent, multi-level pattern of results characterizing the core symptoms of SAD. In future studies, it would be essential to take into account the effects of the potential for interaction in all experimental situations when studying SAD or other disorders associated with abnormalities in social behavior and/or cognition. Our method of using an LC window between two people is a functional paradigm, which can also be used when studying gaze effects in clinical populations.

4.3 Concluding remarks

Taken together, the present findings show that responses to eye contact are influenced by two different factors: 1) the properties of the stimulus, and 2) the observer's mental state. The results suggest that only when both of these factors communicate a potential for interaction, does the body prepares for action. The findings also demonstrate that adolescents with SAD show a consistent physiological, behavioral, and self-assessed response pattern characterizing the core symptoms in SAD, when they are investigated using a live person as a stimulus.

Our studies indicate that the interpretation of gaze plays a major role in bodily responses. Other studies have shown that the interpretation of gaze also plays a major role in many other gaze-affected phenomena (for a recent review, see Hamilton, 2016). However, it is not know for sure how the laboratory environment affects the manner in which gaze stimuli are read. There is a possibility that individuals' sensitivities to a live gaze or their interpretations of a live gaze are different in a laboratory environment than in real life. For example, the reaction to seeing a stranger making eye contact in a cafeteria may be stronger (and different) than a reaction to seeing a stranger making eye contact in a laboratory where gaze effects are investigated. One big challenge for future studies is to develop more ways in which eye contact-related phenomena can be investigated in real life outside of the laboratory (an example of such a study is found in Foulsam, Walker, & Kingstone, 2011).

Eye contact has, indeed, very important functions in human interaction. It is becoming more and more evident that eyes are not only used to send signals, but to discuss with the observer. This work offers important evidence on how eye contact can result in very different consequences depending on the situation and the mental state of the observer. It is not only the informative, but the communicative potential of the eyes that future studies on eye contact and other gaze-related phenomena should concentrate on.

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Cognition 134 (2015) 100–109

Contents lists available at ScienceDirect

Cognition

journal homepage: www.elsevier.com/locate/COGNIT

There is more to eye contact than meets the eye

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ARTICLE INFO

Article history:
Received 10 January 2014
Revised 17 September 2014
Accepted 18 September 2014
Available online 19 October 2014

Keywords:
Gaze direction
Mental attributions
Psychophysiology
Eye contact

ABSTRACT

Recent studies have shown enhanced brain and autonomic responses to seeing a face with a direct gaze. Interestingly, greater responses to eye contact vs. averted gaze have been observed when showing "live" faces as stimuli but not when showing pictures of faces on a computer screen. In this study, we provide unequivocal evidence that the differential responses observed in the "live" condition are dependent on the observer's mental attributions. Results from two experiments showed that eye contact resulted in greater autonomic and brain responses compared to averted gaze if a participant believed that the stimulus person sitting on the other side of an electronic shutter was able to see him or her through the shutter. Gaze direction had no effects if participants believed that the transparency from their side was blocked. The results suggest that mental attributions exert a powerful modulation on the processing of socially relevant sensory information.

1. Introduction

Eye contact with another person can have a strong impact on us. Mutual gazing, in addition to mutual touching, has been suggested to be the only mode of actual encounter between two people in a sense that it is only in these activities that "each person both gives and receives in the same act" (Heron, 1970). Encountering a face with a direct gaze not only elicits affective reactions (autonomic arousal) in the observer (Helminen, Kaasinen, & Hietanen, 2011; Nichols & Champness, 1971) but orients attention, facilitates perception, discrimination and memory of facial information (for a review, see Senju & Johnson, 2009), and modulates even cognitive and affective processing of other information concurrently presented in the vicinity (Conty, Gimmig, Belletier, George, & Huguet, 2010; Strick, Holland, & van Knippenberg, 2008).

However, seeing a pair of eyes does not always mean that one is taking part in social interaction. In everyday life, we see faces with a direct gaze – for example, in magazines, television and advertisements – without encountering any true interaction with another person. It is obvious that it would not be adaptive to react similarly to an unknown face staring at you on the other side of the table and to a face staring at you in a magazine.

In recent years, researchers working in the field of social cognition and social neuroscience have become aware that studying social cognition in the laboratory by showing images of other people to passive observers barely touches upon the psychological processes activated when another person is actually present. Researchers have started to ask if the functioning of the social brain network and associated psychological and physiological responses are the same when the experimental participants are looking at a picture or encountering a real person. Furthermore, if differences do exist, what kind of psychological and neural top-down influences are responsible for this modulation (Hietanen, Leppänen, Peltola, Linna-aho, & Ruuhiala, 2008; Risko, Laidlaw, Freeth, Foulsham, & Kingstone, 2012; Schilbach et al., 2013; Teufel, Fletcher, & Davis, 2010)?

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http://dx.doi.org/10.1016/j.cognition.2014.09.011

In a series of studies from our laboratory, we have reported differences in physiological as well as subjective evaluative responses to seeing a picture of a person on a computer monitor vs. seeing a person "live" through a liquid crystal (LC) shutter. In a "live condition", a direct gaze from another person was shown to elicit larger skin conductance responses (Hietanen et al., 2008; Pönkänen, Peltola, & Hietanen, 2011), larger evoked visual brain responses (Pönkänen, Alhoniemi, Leppänen, & Hietanen, 2011; Pönkänen et al., 2008), and more pronounced left-sided frontal electroencephalographic (EEG) alpha-asymmetry (Hietanen et al., 2008; Pönkänen, Peltola, et al., 2011) associated with approach motivation compared to a person's averted gaze or an inanimate dummy's direct gaze, whereas no effect of gaze direction (Hietanen et al., 2008; Pönkänen, Alhoniemi, et al., 2011; Pönkänen, Peltola, et al., 2011) or nature of the model (i.e., a real person vs. a dummy) (Pönkänen et al., 2008) was observed when looking at these stimuli in a pictorial format. Correspondingly, the subjective evaluations showed more self-assessed arousal (Hietanen et al., 2008) and higher public self-awareness (Pönkänen, Peltola, et al., 2011) for a direct gaze compared to an averted gaze in a "live condition" but not when seeing a picture on a computer monitor. It was suggested that the direct gaze results in these effects only when the observer knows that he/she is being looked at by another "mind". This kind of mentalizing does not occur when facing an image or a non-living stimulus, at least not to the same degree as when facing another "live" person.

Other researchers have shown that visual attention orienting by gaze direction cues is modulated depending on the inferences stemming from the stimulus (e.g. are the observed agent's eyes closed or open) (Nuku & Bekkering, 2008), by the belief of whether the observed person can or cannot see (Teufel, Alexis, Clayton, & Davis, 2010), and by the belief of whether the observed agent is intentional or not (Wiese, Wykowska, Zwickel, & Müller, 2012). Also, sensory visual adaptation to gaze direction stimuli has been shown to be modulated by the mental-state attributions of the observer (Teufel et al., 2009). It has become apparent that social perception is not only about perception of the agent but also about making inferences of the mind of the agent.

In this study we continued to ask the fundamental question of why eye contact with another person has an influence on one's affect and cognition. The studies cited above provide convincing evidence that the mere visual input from a pair of eyes directed to the observer is not enough to explain the phenomenon. In our previous studies, we have suggested that a critical factor is whether the observer has an experience of being seen by another person, being a target of another person's attention (Hietanen et al., 2008; Pönkänen, Alhoniemi, et al., 2011; Pönkänen, Peltola, et al., 2011; Pönkänen et al., 2008).

In the present study, we aimed to isolate the influence of this particular factor while keeping our stimulus presentation condition as natural as possible. To this end, we showed the participants a face of a live model with direct and averted gaze through a liquid crystal (LC) window. In one condition, the participant and the model saw each other through the LC window as usual, whereas in another condition, the participant was led to believe that a half-silvered mirror was placed against the LC window in such a way that the model could not see the participant. In reality no half-silvered mirror was used. In the first experiment we thus investigated whether the participant's belief of whether the model could or could not see him/her influenced the effects elicited by eye contact. In the second experiment we went further and asked how much the "eye contact effect" is, in fact, dependent on seeing the other person's eyes? We manipulated not only the participant's belief of the model's ability to see but also the visibility of the model's eyes by using different types of sunglasses.

2. Experiment 1

To investigate whether autonomic reactivity to eye contact is modulated by the observer's mental state regarding whether he or she (i.e., the self) is being observed by another individual, we measured skin conductance responses (SCR) indexing sympathetic affective arousal (Dawson, Schell, & Filion, 2000), and the heart rate (HR) deceleration response as an index of attention orienting to external stimuli (Graham & Clifton, 1966). Previous experiments have shown that seeing another individual's direct gaze results in larger SCRs compared with seeing an averted gaze (Hietanen et al., 2008; Helminen et al., 2011; Nichols & Champness, 1971; Pönkänen, Peltola, et al., 2011). Faces displaying a direct gaze have also been shown to capture and hold visual attention (Conty, Tijus, Hugueville, Coelho, & George, 2006; Senju & Hasegawa, 2005; von Grünau & Anston, 1995), and there is previous evidence showing that the HR deceleration response, known to be amplified by affectively and motivationally salient stimuli (Bradley, 2009; Lang & Bradley, 2010), is greater in a direct gaze when compared with an averted gaze (Akechi et al., 2013).

In addition to autonomic measures, we also measured various electroencephalographic event-related potentials (ERPs) in order to investigate the time-window in which face and gaze processing becomes affected by top-down processes related to the experience of being seen or not seen. The N170 response and the early centro-parietal and lateral occipito-temporal responses are relatively early components shown to reflect both face and gaze-direction processing (Bentin, Allison, Puce, Perez, & McCarthy, 1996; Conty, N'Diaye, Tijus, & George, 2007; Pönkänen, Alhoniemi, et al., 2011). The mid-latency frontal P3 response is related to attention orientation caused by affectively arousing stimuli (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; Keil et al., 2002) and Conty, N'Diaye, Tijus, and George (2007) have shown that this response is sensitive to gaze directions.

We expected larger SCRs, more pronounced HR deceleration responses, and a larger ERP response to a direct vs. an averted gaze in the condition where the participants believed they were seen by the model. Conversely, we expected the differences in responses to direct vs. averted gaze directions to be reduced or even lacking when the participants believed that the model was not able to see him/her. To supplement the physiological data, we also measured self-assessed social awareness and social presence using the Situational Self-Awareness Scale (SASS) (Govern & Marsch, 2001) and Social Presence Form (SPF) (Short, Willams, & Christie, 1976). Govern and Marsch (2001) have suggested that situational self-awareness consists of three factors: private self-awareness, public self-awareness and awareness of surroundings. Public self-awareness refers to the tendency to attend to aspects of the self that are matters of public display (e.g., overt behavior, mannerisms, expressions), whereas private self-awareness is connected to the tendency to think about more internal aspects of the self (e.g., beliefs, values, feelings). The third factor, awareness of surroundings, refers to the tendency to attend to one's environment (Buss, 1980; Govern & Marsch, 2001). Public self-awareness is also associated with the feeling of being evaluated by another person (Buss, 1980), a feeling which naturally occurs when being looked at by another person. Indeed, previous studies have shown that public self-awareness is greater when being looked at by another (real) person when compared with not looked at Hietanen et al. (2008) and Pönkänen, Peltola, et al. (2011). Heeter (1992) has defined social presence as the sense of "being with others", and Sproull and Kiesler (1986) have suggested that differences in perceived social presence are linked to the amount of social context clues, thus making social presence plausibly connected to being seen – or not being seen – by another person. In line with the physiological measures, we expected the public self-awareness and social presence scores to be higher in the two-way visibility condition when compared with the one-way visibility condition.

2.1. Method

2.1.1. Participants

The participants were 26 right-handed undergraduate students (14 females, 12 males) with normal or corrected-to-normal vision. Five participants (3 females, 2 males) were excluded from the analysis due to not believing in the half-silvered mirror deceit or because they admitted, after the half-silvered mirror condition, that they had forgotten that the model person could not see them. Additionally one female and one male participant were excluded from the ERP analysis and one male from the electrocardiogram (ECG) analysis due to technical error. Hence the final data sample consisted of 21 participants (11 females, 10 males) for the SCR and questionnaire data, 19 participants (10 females, 9 males) for the ERP data and 20 participants (11 females, 9 males) for the ECG data. The ethical statement for the study was obtained from the Tampere Area Ethical Review Board.

2.1.2. Stimuli

A female experimenter acted as a stimulus person. The model person bore a neutral expression and had her gaze either straight ahead or averted 30° to the left or right. The model's face was presented through a voltage-sensitive LC shutter (NSG UMU Products Co., Ltd.). The LC shutter was attached to a black panel positioned between the model and the participant. The size of the shutter window was 30×40 cm. The participant was seated 60 cm from the shutter and the overall distance to the model sitting on the other side was 120 cm.

2.1.3. Experimental procedure

The experiment was conducted in two separate blocks: one for the condition where the participants knew that the model was able to see him/her through the transparent shutter (Belief of being Watched, BW-condition) and another where they believed that the vision of the model was blocked (Belief of not being Watched, BnW-condition). The participants' view (in the sense of retinal image) was identical in the two conditions. Participants were instructed that their task was simply to watch the face of the experimenter while the shutter was open. The deceit was carried out by introducing the participants to a half-silvered mirror type of sheet that was attached to the LC window. A transparent sheet with a thin black frame was slid between the participant and the model so that the participant saw an extra sheet being inserted on the LC window (see Fig. 1, left panel). The participant was then taken to the other side of the shutter. During the walk around the short partition, the model person quickly placed another sheet with an opaque, aluminum-colored surface in front of the LC window (Fig. 1, middle panel). The participant then saw this sheet from the model's side and it was confirmed that it was impossible to see through it (Fig. 1, right panel). When the participant returned to his/her own side of the table, the opaque sheet was cautiously and quickly removed. The presentation order of the conditions (BW-condition/BnW-condition) was counterbalanced across the participants. To control for the suspicion of deceit, the participants were asked after the experiment about their experienced differences between the stimulus presentation conditions. During final debriefing, the deceit was unveiled and the participants were asked directly if they had any doubts about the stimulus person seeing them during the BnW-condition block. The participant was excluded from the analysis if he/she expressed clear doubts of deceit on any of these occasions.

Within each block, two series of measurements were conducted. The first series was intended for the measurements of the SCR and HR responses and it consisted of 16 trials. On eight trials the gaze was direct and on the remaining eight it was averted to the left (four trials) or right (four trials). The presentation order of the stimuli was pseudo-random (no more than two consecutive trials of the same type). The stimulus duration was 5 s with an inter-stimulus interval (ISI) varying between 20 and 45 s. A new trial was allowed after recovery from the previous SCR.

The second series of measurements was to calculate the ERPs and consisted of 160 trials. Of the trials, 80 were with direct gaze and 80 with averted gaze (left or right). The duration of the stimulus presentation was 0.5 s with a 1.5-s ISI. The stimuli were presented in 10-trial sequences repeating the same gaze direction. After each sequence, there was a 15-s break. The order of the 16 sequences was pseudo-randomized so that no more than two consecutive sequences of the same type were allowed.

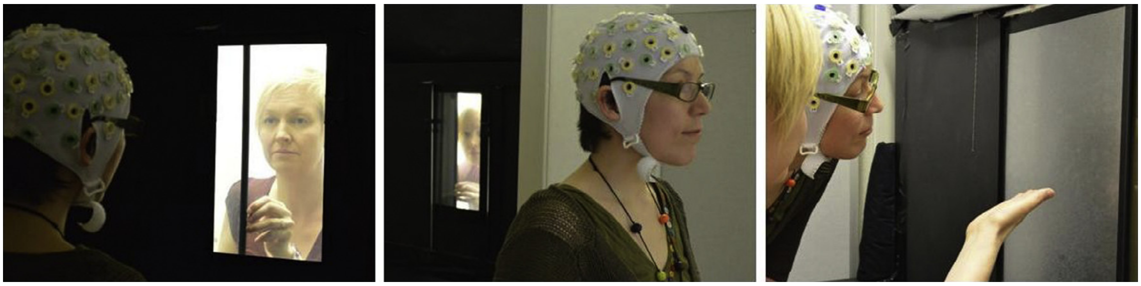

Fig. 1. Illustration of the experimental set-up and the deception procedure. The model slid "half-silvered mirror" (actually a transparent sheet) between a participant and the model (left panel). When the participant was walking to the model's side, the model added quickly another, opaque, sheet in front of the LC-window (middle panel). The participant was convinced that the vision was blocked from the model's side by the "half-silvered mirror" (right panel).

After each block, participants completed two self-assessment questionnaires. The participants were shown a face with a direct gaze (assessments for averted gaze conditions were not collected) for 5 s and then asked to fill in a nine-item SSAS (Govern & Marsch, 2001) and an SPF (Short et al., 1976). SSAS measures three different forms of self-awareness: public self-awareness (e.g., Right now, I am concerned about the way I present myself), private self-awareness (e.g., Right now, I am conscious about my inner feelings) and awareness of the immediate surroundings (e.g., Right now, I am keenly aware of everything in my environment). The SPF was accompanied with an extra item: "I felt very much socially present – I didn't feel socially present at all". Both forms used 7-point scales. Participants were instructed to answer both questionnaires based on their feelings during the previous experimental block, not how they felt in general or at that point in their lives.

2.1.4. Acquisition of the physiological data

For the skin conductance measurements, two electrodes (Ag/AgCl) were attached to the palmar surface of the medial phalanxes of the index and middle fingers of the participant's left hand. For the HR measures, two electrodes (Ag/AgCl) were placed on both arms. The sampling rate for the digitized signals was 1000 Hz.

Continuous EEG was recorded from 64 sites using actiCAP active electrodes, and the signal was amplified with a quickAmp amplifier (Brain products GmbH, Munich, Germany). An average reference was used. The sampling rate for the digitized signal was set to 1000 Hz. Additionally, vertical (VEOG) eye movements were recorded above and below the left eye. Skin abrasion and electrode paste were used to reduce electrode impedances below 25 kOhm.

2.1.5. Data analysis

The SCR data were re-sampled offline to 100 Hz and filtered with a 10 Hz low-pass filter. No high-pass filtering was used. The skin conductance response was defined as a maximum amplitude change from the baseline level (at the stimulus onset) during a 4-s time period starting 1 s after the stimulus onset. In case there was more than a 0.1 μS amplitude rise during the first second after stimulus onset, the trial was rejected. Of all trials, 7.7% was eliminated due to this criterion or because of a technical error. The data were averaged for each condition and gaze direction for each participant, including those with maximum amplitude below 0.01 μMho (i.e. zero responses); this calculation results in the *magnitude* of the skin conductance responses; a measure that combines response size and response frequency (cf., Dawson et al., 2000).

The ECG data were analyzed offline with an in-house (Matlab-based) algorithm to measure the time intervals between two successive R-waves (inter-beat interval, IBI). Trials with excessive distortion in the signal were excluded from the analysis (1.9% of the trials). For a period between 5 s pre-stimulus and 10 s post-stimulus within each trial, the IBIs were quantified and assigned to 1-s intervals. Lastly, IBIs were converted to beats per minute (bpm) and averaged across trials within each condition. A baseline was defined as the average of the IBIs during the 5-s pre-stimulus period. The analyses were performed with HR-change scores that were calculated by subtracting the bpm of each post-stimulus 1-s interval from the baseline.

The continuous EEG signal was offline-filtered with 0.5–30 band-pass filter with 24 dB/oct slope on both ends. The filtered signal was ocular-corrected using a Gratton/Coles algorithm and manually checked for artifacts. In order to study the ERP responses, the signal was segmented into 600-ms long epochs starting 100 ms before the stimulus onset and computed for each condition and gaze direction. The baseline was computed from the 100-ms pre-stimulus period.

In order to study the ERP responses, the signal was segmented into 600-ms long epochs starting 100 ms before the stimulus onset and computed for each condition and gaze direction. The baseline was computed from the 100-ms pre-stimulus period. We analyzed the early N170 response and early centro-parietal and lateral occipito-temporal activity (Conty, N'Diaye, Tijus, & George, 2007; Pönkänen, Alhoniemi, et al., 2011), and the mid-latency frontal P3 response (Cuthbert et al., 2000; Keil et al., 2002).

For the N170 analysis, we pooled the data over three electrodes located in the occipito-temporal region of the right and left hemispheres. These electrodes were PO8/7, P8/7 and P6/5. The minimum amplitude peaks were then identified within a time window of 110–180 ms for each participant in each condition.

Secondly, we analyzed the centro-parietal and left and right lateral occipito-temporal activity during and shortly after the N170 response. Visual inspection showed very similar activity in the centro-parietal electrodes and we decided to pool data over six electrodes (C1, CP1, Cz, CPz, C2 and CP2). On left and right lateral occipito-temporal areas, we pooled the data over electrodes (TP9, TP7 and P7) and (TP10, TP8 and P8). For all three scalp regions, we measured the mean amplitude between 160 and 300 ms separately for each participant in each condition.

Third, we analyzed the frontal P3 component. We analyzed right and left anterior frontal and frontal pole regions averaged over electrodes (AF3, AF7 and Fp1) and (AF4, AF8 and Fp2) and measured the mean amplitude between 200 and 450 ms post-stimulus for each participant in each condition. In addition to the frontal P3, we checked the P3 responses from the central and parietal areas (at and around channels Cz and Pz). However, visual inspection did not show any signs of effects for gaze direction or state of belief and we did not perform any further analyses.

All statistical analyses were conducted using repeated measures ANOVA. Planned comparisons were performed for the analysis of simple main effects when interactions were observed. A Greenhouse–Geisser correction procedure was applied when appropriate. SCR and HR data were not normally distributed and were normalized using ln-transformation. In Section 3, Figs. 2 and 3 show the statistics based on the untransformed values. All analyses were done to normally distributed variables.

2.2. Results

Fig. 2 shows the mean SCR values for each gaze direction in the BW and BnW-conditions. The SCR were subjected to an analysis of variance (ANOVA) with state of belief (BW-condition, BnW-condition) and model's gaze direction (direct, averted) as within-subjects factors. The ANOVA indicated significant main effects for gaze ($F_{(1,20)} = 5.4$, $p = .03$, $\eta^2_p = 0.21$) and for state of belief ($F_{(1,20)} = 4.9$, $p = .04$, $\eta^2_p = 0.20$). Importantly the interaction between the main effects was significant ($F_{(1,20)} = 5.8$, $p = .03$, $\eta^2_p = 0.23$). Pairwise comparisons indicated that the SCR was greater for direct gaze compared to averted gaze in the BW-condition ($t = 3.2$, $df = 20$, $p < .01$, $d = 0.70$) but not in the BnW-condition ($t = .40$, $df = 20$, $p = .70$, $d = 0.09$).

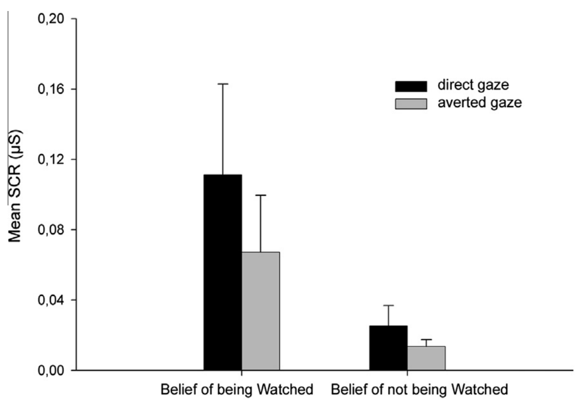

Fig. 2. Skin conductance responses (mean + s.e.m.) to direct and averted gaze in two presentation conditions. In the BW-condition, the model and the participant both saw each other. In the BnW-condition, the participant believed that a half-silvered mirror prevented the model from seeing him/her.

The HR-change scores are presented in Fig. 3. The results showed an HR deceleration response in all conditions. The HR scores were subjected to a 2 × 2 × 10 ANOVA, with state of belief, gaze direction and the time interval after the stimulus onset (0–1 s, 1–2 s,...,9–10 s) as within-subjects factors. The ANOVA revealed a main effect for gaze ($F_{(1,19)} = 4.7$, $p = .04$, $\eta^2_p = 0.20$) and time ($F_{(9,19)} = 36.4$, $p < .001$, $\eta^2_p = 0.91$) as well as an interaction between state of belief and gaze ($F_{(1,19)} = 19.3$, $p < .001$, $\eta^2_p = 0.50$). When analyzing the state of belief conditions separately (data averaged across time-points), *t*-tests indicated that the HR deceleration was more prominent for direct than averted gaze ($t = 3.5$, $df = 19$, $p = .002$, $d = 0.79$) in the BW-condition, whereas the difference was not significant ($t = 0.1$, $df = 19$, $p = .91$, $d = 0.03$) in the BnW-condition.

For cortical ERP-responses, we first analyzed the face-sensitive N170 responses recorded from the occipito-temporal regions. The stimuli elicited clear N170 responses in all conditions. However, an ANOVA revealed no main effects (state of belief, gaze direction and hemisphere) or interactions (all *p*s > .1).

The mean amplitude between 160 and 300 ms post-stimulus was analyzed over the centro-parietal electrodes and the right and left lateral occipito-temporal electrodes. A 2 × 2 × 3 ANOVA having state of belief, gaze direction and scalp region (right, central, left) as within-subjects factors showed an interaction between gaze direction and scalp region ($F_{(2,36)} = 18.9$, $p < .001$, $\eta^2_p = 0.44$). Further analyses showed that direct gaze induced a more negative response compared to averted gaze over the centro-parietal region ($t = -2.8$, $df = 18$, $p = .012$, $d = 0.62$), whereas this polarity difference was reversed over the right occipito-temporal site ($t = 6.4$, $df = 18$, $p < .001$, $d = 1.31$). Gaze direction had no effect on the responses measured over the left occipito-temporal region ($t = 0.4$, $df = 18$, $p = .723$, $d = 0.03$). State of belief or any other conditions were not significant. The grand-averaged ERPs are illustrated in Fig. 4.

For the frontal P3 component (mean amplitude between 200 and 450 ms post-stimulus), a 2 × 2 × 2 ANOVA (state of belief × gaze direction × hemisphere) revealed the main effects of gaze direction ($F_{(1,18)} = 8.7$, $p < .01$, $\eta^2_p = 0.33$) and hemisphere ($F_{(1,18)} = 37.0$, $p < .001$, $\eta^2_p = 0.67$). Importantly there was an interaction between gaze direction and state of belief ($F_{(1,18)} = 5.6$, $p = .03$, $\eta^2_p = 0.24$). Pairwise comparisons showed that in the BW-condition, the P3 response (averaged across hemispheres) was significantly shifted in the positive direction to direct vs. averted gaze ($t = 3.5$, $df = 18$, $p < .01$, $d = 0.80$), whereas in the BnW-condition, such an effect was not present ($t = 1.1$, $df = 18$, $p = .31$, $d = 0.24$). The grand averaged P3 ERPs are presented in Fig. 5.

For self-assessment ratings, a *t*-test indicated stronger public self-awareness in the BW-condition than in the BnW-condition ($t = 2.5$, $df = 20$, $p < .05$, $d = 0.56$). For private self-awareness and awareness of immediate surroundings, no significant differences were found. Self-assessed social presence was stronger in the BW-condition compared to the BnW-condition ($t = 3.1$, $df = 20$, $p < .01$, $d = 0.68$) (Table 1).

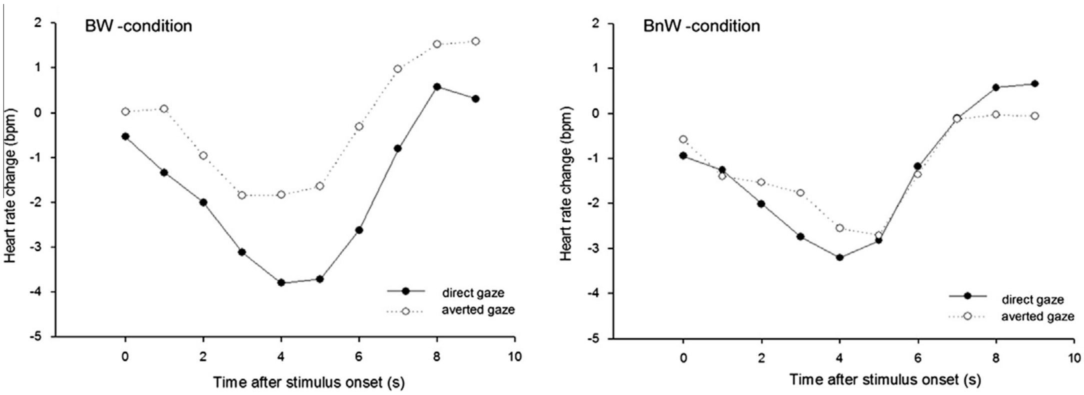

Fig. 3. Heart rate changes in relation to direct and averted gaze in two presentation conditions.

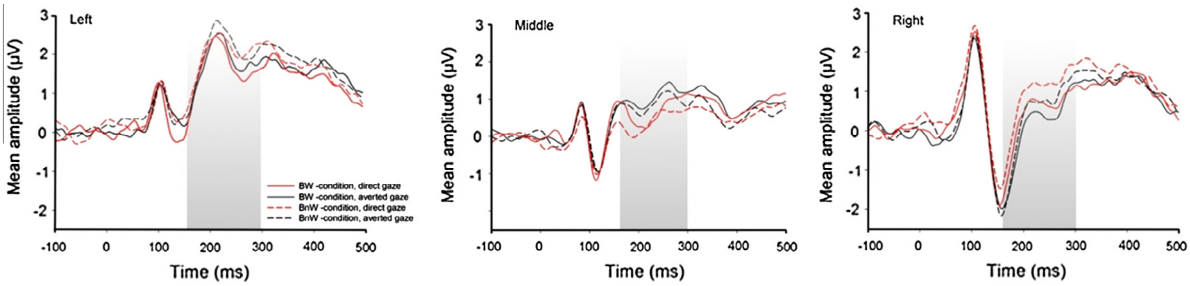

Fig. 4. Grand-averaged ERP waveforms to direct and averted gaze in two presentation conditions. Waveforms are separately presented for centro-parietal (middle) and for left and right temporo-parietal electrode sites. The shaded area shows the time frame of interest (160–300 ms).

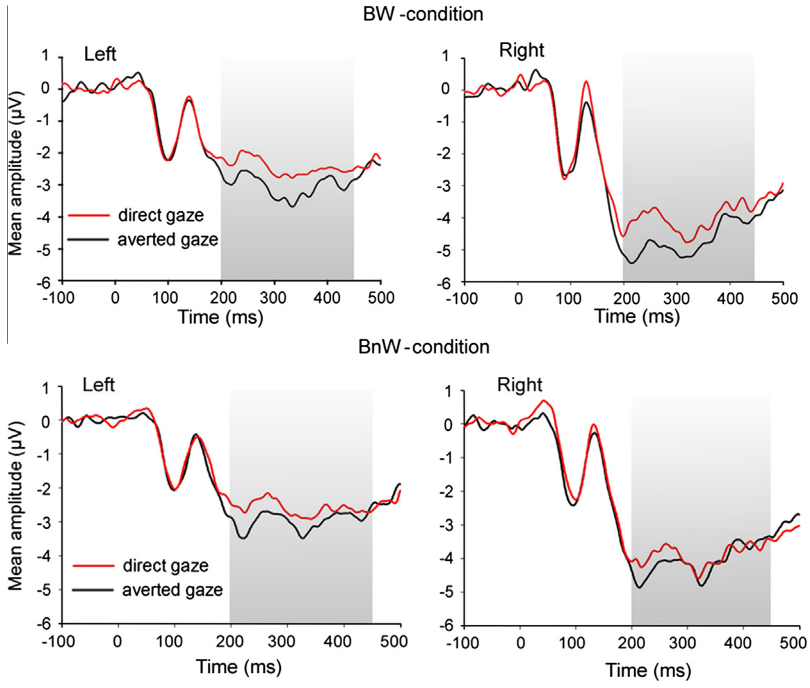

Fig. 5. Grand averaged frontal P3 waveforms to direct and averted gaze in two presentation conditions. Waveforms are separately presented for left and right frontal electrode sites. The shaded area shows the time frame of interest (200–450 ms).

Table 1
Self-rated SSAS (Situational Self-Awareness Scale) and social presence (SPF) scores for two different presentation conditions. The SSAS scores include three factors of self-awareness (public, private, and surroundings). Scale range in all scores is 1–7.

Presentation condition	Public		Private		Surroundings		Social presence	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
BW-condition	2.73	1.47	3.56	1.31	3.33	1.29	4.06	0.94
BnW condition	2.15	1.12	3.67	1.29	3.23	1.19	3.63	0.94

In order to analyse, whether public self-awareness and social presence were influencing the physiological responses, we analyzed the correlations between public self-awareness and SCRs and between social presence and SCRs (separately in the two state of belief conditions and for the two gaze directions). In the BW-condition, the correlations suggested that participants reporting higher levels of public self-awareness had greater SCRs. This applied both to direct and averted gaze. However, the evidence was not strong as the correlations only approached statistical significance ($r_{\text{DirectGaze}} = .356$, $p = .081$) and ($r_{\text{AvertedGaze}} = .347$, $p = .089$). The corresponding correlations in the BnW condition were not significant ($ps > .2$). For social presence, the corresponding analyses showed no connection between social presence and SCRs (all $ps > .2$).

3. Experiment 2

In Experiment 2, we wanted to investigate whether the "eye contact effect" observed in Experiment 1 was dependent on seeing the other person's eyes. Senju and Johnson (2009) defined the eye contact effect as "the phenomenon that perceived eye contact modulates the concurrent and/or immediately following cognitive processing and/or behavioral response", and their fast track modulator model postulates that eye contact effect relies on the processing of visual information from the eyes by subcortical mechanisms, which then modulate the cortical processing. However, as the results of Experiment 1 showed, the enhancement of the autonomic and cortical responses to direct gaze was entirely dependent on the participants' beliefs about being seen, thus the findings prompt one to ask what kind of a role the eyes play as a visual stimulus in the observed results. If the critical factor is an observer's experience of being watched or not, then the visibility of another individual's eyes is perhaps not necessary. In Experiment 2, we manipulated not only the participant's belief in the model's ability to see the participant, but also the visibility of the model's eyes. In three different experimental blocks, a new sample of participants saw a live model with a direct or averted head orientation. In each block, the model wore a different pair of sunglasses: a pair without lenses so the model's eyes were visible; a pair of normal sunglasses with dark lenses; and a pair with blocked lenses so the model could not see through them. The normal and blocked sunglasses looked identical to the participants. The participants were always informed of which sort of glasses the model was wearing. In this experiment, we only measured the affective autonomic responses (SCR). If the autonomic response is dependent on seeing the eyes, we should not expect to observe differences in SCRs between direct and averted head orientation in the two conditions obscuring the visibility of the eyes. However, if the experience of being seen by another person is crucial for the enhanced autonomic responses, we should expect to observe larger responses to a direct vs. averted head orientation regardless of the visibility of the model's eyes, so long as the observer knows that the other person is able to see him or her. We therefore expected to observe the latter pattern of results.

3.1. Method

3.1.1. Participants

The participants were 24 undergraduate students (13 females, 11 males, mean age 27.0 years, range 21–53 years) with normal or corrected-to-normal vision. The ethical statement for the study was obtained from the Tampere Area Ethical Review Board.

3.1.2. Stimuli

The stimulus was the face of an assisting experimenter (male or female). Half of the participants saw a male face and the other half saw a female face. The sex of the participants was balanced with respect to the sex of the model person. The model person had a head orientation either straight ahead or rotated 30° to the left or right. The model always looked in the same direction where his/her head was oriented. In this experiment, the stimuli were presented normally through the LC window. The half-silvered mirror deceit procedure was not used here. Otherwise the stimulus presentation was as in Experiment 1.

3.1.3. Experimental procedure

The experiment included three experimental blocks. In one block, the model wore dark sunglasses, thus obscuring his or her eyes. In the second block, the model wore similar sunglasses, but the insides of the lenses were covered so that it was impossible to see through them. The external view of the sunglasses in these two blocks looked exactly the same. In the third block, the model wore a similar pair of sunglasses but with the lenses removed, thus allowing the eyes to be seen. Before the experiment, the participants were allowed to examine the different sunglasses/frames to convince them that it was possible to see through the normal sunglasses while it was impossible to see through the covered ones. The presentation order of the blocks was counterbalanced across the participants.

There were 12 trials within each block. For six trials, the model's head was oriented directly toward the participant and for the remaining six trials it was rotated to the left or right. Within a block, the presentation order of stimuli was pseudo-random (no more than two consecutive trials of

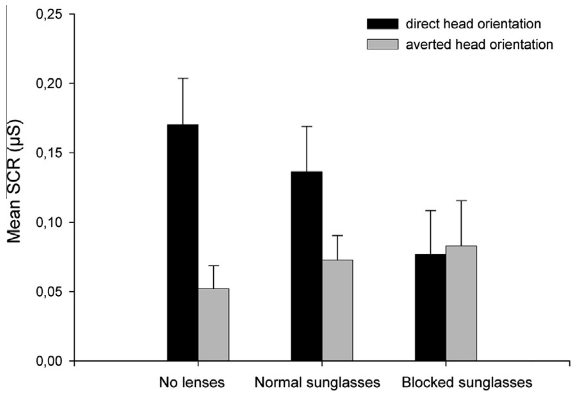

Fig. 6. Skin conductance responses (mean + s.e.m.) to direct and averted gaze in three presentation conditions (Experiment 2). In the "no lenses" condition, participants saw a model wearing sunglasses frames without lenses (eyes visible). In the "normal lenses" condition, a model was wearing normal sunglasses (eyes not visible, but the model saw through the lenses). In the "blocked lenses" condition, a model was wearing sunglasses with the lenses blocked from the inside (eyes not visible, the model could not see through the lenses).

the same type). The stimulus duration was 3 s with an ISI varying between 20 and 45 s. A new trial was allowed after recovery from the previous SCR.

3.1.4. Acquisition of the physiological data and data analysis

The SCR data were acquired and analyzed in a similar manner as for Experiment 1. From all the trials, 11.2% was eliminated due to responding too early or a technical error.

3.2. Results

The SCRs were analyzed using a 2 × 3 within-subjects ANOVA. The ANOVA indicated a main effect of head orientation ($F_{(1,23)} = 9.0$, $p < .01$, $\eta^2_p = 0.29$) and an interaction between head orientation and sunglass condition ($F_{(2,46)} = 4.1$, $p = .033$, $\eta^2_p = 0.16$). When analyzing the three sunglass conditions separately, *t*-tests indicated larger SCRs to direct vs. averted head orientation when the glasses had no lenses ($t = 3.4$, $df = 23$, $p < .01$, $d = 0.68$) and when the lenses were normal ($t = 3.2$, $df = 23$, $p < .01$, $d = 0.67$) but not when the lenses were blocked ($t = 0.4$, $df = 23$, $p = .72$, $d = 0.07$). The SCRs to direct head orientation were not significantly larger when the eyes were visible (no lenses) compared with when they were covered by normal sunglasses ($t = 0.7$, $df = 23$, $p = .50$, $d = 0.14$). However, the SCRs to direct head orientation in both of these conditions were larger than the SCRs to direct head orientation when the model wore blocked lenses (both *p*s < .02). The mean SCR values in all three conditions are shown in Fig. 6.

4. Discussion

The results unveiled an intriguing interplay between gaze direction and mental attributions affecting physiological and self-assessed responses. Autonomic SCRs and HR deceleration responses were larger and the cortical P3 response was more positive for direct gaze than for averted gaze, but only when the participants believed that the model could see him/her. To complete the consistent pattern of physiological results, the subjective ratings showed higher levels of public self-awareness and social presence when the model was able to see the participant compared with when the model was not. Based on the results of our earlier studies demonstrating differences in physiological and self-assessed measures in response to seeing a real person and seeing a picture (Hietanen et al., 2008; Pönkänen, Alhoniemi, et al., 2011; Pönkänen, Peltola, et al., 2011; Pönkänen et al., 2008), we have hypothesized that the critical factor may be the observer's knowledge of being the target of another individual's attention or not. The present findings provide strong support for this hypothesis and provide further evidence that top-down influences have a major role in governing the reactions to another person's eye gaze.

We argue that the presence of another individual who has the potential to see and attend to an observer initiated mentalizing in the observer. In this situation, if the observer detected that the other individual's attention was directed to himself/herself, the observer was prone to viewing himself/herself in the second person perspective. The "self" was experienced as the object of another's attention (cf., Reddy, 2003). Specifically, in our study, this heightened the observer's public self-awareness (but not private self-awareness or awareness of surroundings) as well as feelings of social presence. Concomitant with the psychological-level reactions, a "true" eye contact also resulted in enhanced autonomic responses associated with affective arousal (SCR) and attention allocation (HR deceleration) as well as cortical responses (P3) reflecting attention orienting by motivationally salient stimuli. On the other hand, if the observer knew that the other individual was not able to see him/her, the other individual's gaze direction had no effects on the subjective evaluations or physiological responses. Taken together, the present findings provide strong evidence that the observer's knowledge of being the target of another individual's attention or not has a major role in governing the reactions to another person's eye gaze. We also suggest that enhanced self-awareness due to mutual eye contact may play a central role in the observed eye contact effect.

We were also able to show that the visibility of the other person's eyes, in fact, may not be necessary at all in order to observe the "eye contact effect". We observed larger SCRs to direct head/gaze vs. averted head/gaze both when the model was wearing sunglasses without lenses and also when wearing sunglasses with normal dark lenses hiding the eyes. Additionally the autonomic response to direct head/gaze was not stronger when the model's eyes were visible compared to when the model wore normal sunglasses. Thus, seeing the other person's eyes seems to play a negligible role in the "eye contact effect". However, cautiousness is required when interpreting this last result: it is possible that the experiment was not sensitive enough to reveal the difference between visible and non-visible direct eyes. The discriminative sensitivity was maximal for conditions presented within a block (i.e., direct vs.

averted gaze) but not for between-block conditions. Future studies must resolve whether the visibility of the eyes contributes further to the strength of the measured responses or not.

Regarding the cortical brain responses, the results replicated earlier results showing that the N170 response suggested to reflect the structural coding of the face (Bentin et al., 1996) was not sensitive to the gaze direction (Pönkänen et al., 2008; Taylor, Itier, Allison, & Edmonds, 2001), although, in some studies, gaze direction effects on N170 have been reported (Conty et al., 2006; Puce, Smith, & Allison, 2000; Pönkänen, Alhoniemi, et al., 2011). However, another early component measured from the centro-parietal and temporal regions during the time interval of 160–300 ms post-stimulus discriminated between the direct and averted gaze. This differential cortical activity between gaze directions was observed regardless of the participant's state of belief. Similar differences between gaze directions on cortical activity at this latency range have previously been reported for typically developed children (Senju, Tojo, Yaguchi, & Hasegawa, 2005) and adults (Conty et al., 2006). It has been suggested that this component may reflect additional face-related processes taking place during N170, but being distinct from it (Conty et al., 2006; Senju et al., 2005). As we observed gaze direction sensitivity on these centro-parietal and temporal cortical channels in the absence of N170 effects, our results build on the evidence for this suggestion.

The frontally measured P3 response considered to reflect attention orienting by affectively arousing stimuli (Cuthbert et al., 2000; Keil et al., 2002) was more positive to direct gaze vs. averted gaze only when the participant knew that the model was able to see him/her. This result combined with the other observed ERP results suggests that the presently investigated top-down influences do not modulate the more posterior ERP responses reflecting lower stages of visual information processing, but exert their influence on higher stages of processing. At first, this may seem contradictory considering, for example, the recent results showing the influences of mental-state attributions on sensory visual adaptation to gaze direction stimuli (Teufel et al., 2009). Experiments combining gaze direction adaptation and functional magnetic resonance imaging (fMRI) have localized these effects to the human superior temporal sulcus (STS) (Calder et al., 2007). However, the studies using fMRI have not revealed the time-course of the gaze direction adaptation effect. Thus, mentalization may exert its effect on the gaze direction processing in the STS, but not on the early stages of processing. Naturally, more research is needed to resolve how strongly and how early top-down influences can affect different types of cortical social information processing.

Neuroimaging evidence suggests that medial prefrontal cortex (mPFC) activation is linked to mentalization processes and feelings of involvement in social interaction (Amodio & Frith, 2006; Schilbach et al., 2006), and it has been proposed that the mPFC plays a prominent role in modulating the processing of visual information in a social context (Schilbach et al., 2013; Teufel, Fletcher, et al., 2010). It is possible that the "state of belief" modulation effects on the observed physiological responses may reflect the effect of the mPFC modulation. A theoretically interesting question is, of course, whether the observed response modulations reflect direct effects by mentalization or whether they are mediated by some other intervening mechanisms. As suggested in our earlier study (cf. Pönkänen, Alhoniemi, et al., 2011), these types of effects could be related to the potential for interaction between the participant and the model. For example, Shimada and Hiraki (2006) have shown that participants' sensory-motor brain activity is enhanced in response to the viewing of human actions vs. viewing object movement when both stimulus types are presented in a live setting, but not when presented on a screen. Thus, it is possible that participants experienced greater interaction potential in the belief of being watched (BW) condition than in the belief of not being watched (BnW) condition. Another possibility is that the observed effects were mediated by so-called audience effects, including concerns about one's reputation in the eyes of another individual (Frith & Frith, 2012). The audience effect in our experimental situation can be interpreted as one example of mentalizing processes; it was also likely to be greater in the BW than in the BnW condition. An additional possibility relates to attentional effects. Looking at another individual's direct gaze is likely to result in greater allocation of attentional resources when one knows that one is being watched oneself vs. when one is not being watched. In any case, it is important to note that whatever the involved mechanisms are, the core factor is likely to be related to whether one is being watched by another individual or not.

As this and several other recent studies show, the human visual information processing does not depend only on the input, the retinal image, but also on the higher-order processes such as the mental attributions taking place in the experimental situation. We want to emphasize that we are not arguing that this type of top-down modulation occurs only when facing a real person who is physically present: several studies show that it can also be observed when participants are looking at another person via video-link or even when looking at inanimate stimuli (Nuku & Bekkering, 2008; Teufel, Alexis, et al., 2010; Teufel et al., 2009; Wiese et al., 2012) but it may be the case that the use of less natural social stimuli does not elicit such robust top-down effects, or does so perhaps only in the minority of participants, as does the use of more natural stimuli. The present results provide strong evidence that these types of processes have a profound impact on the processing of social information.

An interesting topic for future studies will be to investigate more extensively the modulatory effects that top-down influences can have on a variety of processes involved in gaze, face and body perception. It is also imperative to examine e.g. to what degree it is possible to voluntarily control the activation of different types of mentalization processes, what kind of factors are critical in elicitation of this kind of mentalization and whether the consequences of "simulated mentalization" are similarly observed in the context of spontaneously occurring mentalization. This kind of research can potentially have a great impact on our understanding of social perception.

Acknowledgement

This work was supported by the Academy of Finland (Project # 266187 to J.K.H.).

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Social Cognitive and Affective Neuroscience Advance Access published July 1, 2015

OXFORD

Social Cognitive and Affective Neuroscience, 2015, 1–7

doi: 10.1093/scan/nsv075
Original article

The dual nature of eye contact: to see and to be seen

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Abstract

Previous research has shown that physiological arousal and attentional responses to eye contact are modulated by one's knowledge of whether they are seen by another person. Recently it was shown that this 'eye contact effect' can be elicited without seeing another person's eyes at all. We aimed to investigate whether the eye contact effect is actually triggered by the mere knowledge of being seen by another individual, i.e. even in a condition when the perceiver does not see the other person at all. We measured experienced self-awareness and both autonomic and brain activity responses while participants were facing another person (a model) sitting behind a window. We manipulated the visibility of the model and the participants' belief of whether or not the model could see them. When participants did not see the model but believed they were seen by the model, physiological responses were attenuated in comparison to when both parties saw each other. However, self-assessed public self-awareness was not attenuated in this condition. Thus, two requirements must be met for physiological responses to occur in response to eye contact: an experience of being seen by another individual and an experience of seeing the other individual.

Key words: eye contact; skin conductance; heart rate; EEG; interaction

Introduction

Eye contact is a powerful signal which modulates social cognition as well as autonomic responses and brain activity in many ways. For example, faces with direct gaze are memorized more readily than faces with averted gaze (Mason *et al.*, 2004), and faces with direct gaze can better hold attention, detracting from performance in concurrent cognitive tasks (Senju and Hasegawa, 2005; Conty *et al.*, 2010). Seeing a face with direct *vs* averted gaze results in stronger autonomic responses as measured by skin conductance (Nichols and Champness, 1971; Helminen *et al.*, 2011, 2015) and heart rate deceleration (Akechi *et al.*, 2013). Neuroimaging studies have revealed stronger activation in response to faces with direct *vs* averted gaze in several brain areas, including the fusiform gyrus (George *et al.*, 2001; Calder *et al.*, 2002; Pageler *et al.*, 2003;), superior temporal sulcus (Calder *et al.*, 2002; Wicker *et al.*, 2003), medial prefrontal cortex (Schilbach *et al.*, 2006), orbitofrontal cortex (Wicker *et al.*, 2003; Conty *et al.*, 2007) and amygdala (Kawashima *et al.*, 1999; Sato *et al.*, 2004). Interestingly, it has been shown that the amygdala activates more strongly in response to direct than averted gaze even if the individual lacks conscious visual experience due to destruction of the primary visual cortex (i.e. cortical blindness; Burra *et al.*, 2013).

Recently, several studies have shown that the effects of seeing a direct *vs* averted gaze may depend on whether participants are presented a real person or a picture or a video of a face. Compared with averted gaze, looking at direct gaze of a 'live' person has been shown to elicit larger skin conductance responses (SCR) (Hietanen *et al.*, 2008; Pönkänen *et al.*, 2011b), larger visual brain responses (Pönkänen *et al.*, 2011a) and more pronounced relative left-side frontal electroencephalographic (EEG) alpha activity associated with approach motivation (Hietanen *et al.*, 2008). Additionally, self-assessed public self-awareness (a tendency to attend to the aspects of the self that are on public display) has also been shown to be greater for direct than averted gaze when looking at a real person (Hietanen *et al.*, 2008; Pönkänen *et al.*, 2011b). Importantly, all these differences in physiological and self-assessed measures in response to direct *vs* averted gaze were observed only for real 'live' stimuli, and not for pictures of faces. It was suggested that one's

Received: 9 April 2015; **Revised:** 26 May 2015; **Accepted:** 4 June 2015

knowledge of being looked at by another person may be the pivotal factor modulating these responses to social stimuli (Hietanen *et al*., 2008; Pönkänen *et al*., 2011b). Supporting this suggestion, it has been shown that attention orienting by gaze cues (Teufel *et al*., 2010) and sensory visual adaptation to gaze direction stimuli (Teufel *et al*., 2009) are modulated by the belief of whether the stimulus-person can or cannot see the observer.

One plausible factor for the differential effects of gaze direction between a live gaze and a picture may be whether participants experience being observed by the stimulus person. In our recent study, we isolated and manipulated this factor while keeping other stimulus properties unchanged (Myllyneva and Hietanen, 2015, Experiment 1). We used a live person as the stimulus (model) and used a deception procedure to manipulate participants' belief of whether they could be seen by the model. Importantly, the visual conditions were identical to the participants. Only when participants thought that they could be seen by the models did direct gaze elicit greater skin conductance and heart rate deceleration responses, pronounced EEG frontal P3 responses and higher public self-awareness. These results provided strong evidence that knowledge of being looked at by another person is an important factor underlying the enhanced responses to direct gaze.

If knowledge of being looked at is a key factor underlying enhanced physiological responses to eye contact, one can ask if seeing one's eyes is even necessary to elicit the 'eye contact effect'. We addressed this question in a second experiment (Myllyneva and Hietanen, 2015, Experiment 2) wherein we not only manipulated participants' beliefs of being seen by the model but also the visibility of the model's eyes by using different sunglasses. The results showed enhanced SCRs to direct gaze/head orientation independent of whether the model's eyes were visible as long as participants knew that the model was able to see. However, when the model's eyes were not visible and the participant was told that the model was not able to see through the sunglasses, the SCRs to direct head orientation were attenuated. These results provided further evidence that the critical factor behind the enhanced physiological responses is not eye contact *per se*, but rather the awareness that one is being observed by another person.

These findings motivated the present experiment in which we took one further step and asked whether it is possible to observe the physiological responses to being seen by another person even when the other person is not visible at all. There is substantial evidence indicating that the autonomic nervous system can be activated without presenting sensory stimuli. For example, emotional and motor imagery tasks have been shown to result in similar autonomic activation compared with emotional sensory stimuli or actual motor performance, respectively (for reviews see: Lang, 1979; Guillot and Collet, 2005; Kreibig, 2010). It has also been shown that mental imagery can modulate cortical activity. For example, imaging faces has been shown to produce similar modulation of the face-sensitive N170 EEG response as seeing actual faces (Ganis and Schendan, 2008). In the present experiment, we compared physiological and self-evaluated responses in three different experimental conditions: (i) when the participant and the model could both see each other, (ii) when the participant could not see the model but was led to believe that the model could see him/her and (iii) when the participant could not see the model and was led to believe that the model also could not see him/her.

Following our previous study (Myllyneva and Hietanen, 2015), we measured SCR, heart rate deceleration responses, frontal P3 evoked-response potentials (ERP) and situational self-awareness. SCR index sympathetic affective arousal (Dawson *et al*., 2000), whereas the heart rate deceleration response is associated with orienting attention towards external stimuli (Graham and Clifton, 1966). The mid-latency frontal P3 ERPs analysed from the EEG signal are related to attention orientation caused by affectively arousing stimuli (Cuthbert *et al*., 2000; Keil *et al*., 2002). Self-assessed situational self-awareness consists of three components: private self-awareness, public self-awareness and awareness of one's surroundings (Govern and Marsch, 2001). The component potentially sensitive to being observed by another person is public self-awareness because it is associated with the feeling of being evaluated by another person (Buss, 1980). Previous research has shown stronger responses to direct than averted gaze in SCR (Nichols and Champness, 1971; Hietanen *et al*., 2008; Helminen *et al*., 2011), heart rate deceleration response (Akechi *et al*., 2013), P3 ERP component (Conty *et al*., 2007) and public self-awareness (Hietanen *et al*., 2008; Pönkänen *et al*., 2011b). Importantly, these four measures were all analysed in our previous experiment (Myllyneva and Hietanen, 2015), where they were found to be modulated by participants' beliefs of whether they were being observed by the model.

We made a straightforward hypothesis: we predicted greater skin conductance, HR deceleration responses and self-assessed public self-awareness when participants thought they were being observed compared with when they thought they were not being observed, regardless of whether the other person was visible. We expected P3 responses to be strongly modulated by the visual stimulus, but also expected to see a shift in the positive direction when participants believed that they were being observed, even when they did not see the other person at all.

Materials and methods

Participants

The participants were 25 right-handed undergraduate students (15 females, 10 males) with normal hearing and normal or corrected-to-normal vision. Seven female participants were excluded from the electrocardiogram (EKG) and SCR analyses due to an error in the script of the computer program causing data not to be recorded. Additionally, two male participants and three female participants were excluded from the P3 analysis due to excessive artefacts. Hence, the final data sample consisted of 25 participants for the questionnaire data, 18 participants (8 females, 10 males) for the SCR and EKG data and 20 participants (12 females, 8 males) for the ERP data. Ethical approval for this study was obtained from the Tampere Area Ethical Review Board. Participant consent was obtained according to the Declaration of Helsinki.

Stimuli

One-half of the female and male participants saw a male experimenter and the other half saw a female experimenter as the stimulus person (model). The model bore a neutral expression on his/her face and had a direct gaze. The model's face was presented through a computer-operated voltage-sensitive liquid-crystal (LC) window (NSG UMU Products Co., Ltd.). The LC window was attached to a black panel positioned between the model and the participant. The size of the LC window was 30×40 cm. The participant was seated 60 cm from the window and the overall distance to the model sitting on the other side was 120 cm. Because the participants did not see the model in all conditions, a muffled buzzing sound was always presented to indicate the occurrence of the trial. The same buzzing sound was presented in all three blocks of trials (see below). The volume of the sound was set to be unobtrusive, but easily audible. The buzzing sound lasted until the offset of the trial.

Experimental procedure

The experiment was conducted in three separate blocks, one for each condition: (i) the participant (P) and the model (M) could see each other (P+/M+), (ii) the participant did not see the model, but believed that the model saw him/her (P−/M+) and (iii) neither the participant nor the model saw the other (P−/M−). Participants were instructed that their task was simply to watch forward, towards the panel behind which the model was sitting, independent of whether the participant could see the model or not. Participants were told that the model will be also watching the panel during all conditions. As described above, during the trials, a buzzing sound indicated when the LC-window was transparent.

In the P+/M+ condition, the model was presented through the LC window in such a way that both the participant and the model were able to see each other when the LC window became transparent. The P−/M+ condition was carried out by a deception procedure in which the participant was led to believe that a half-silvered 'one-way' mirror was attached to the LC window. While the participant was sitting in his/her seat and the LC window was transparent, the model slid an opaque, aluminum-coloured sheet onto the window and the participant was told that now the participant could not see the model but that model was still able to see them. To convince the participant, he/she was then taken to the other side of the LC window panel. While the participant was walking around the short partition, the model quickly replaced the opaque sheet with another sheet that was transparent. The participant then saw this transparent sheet from the model's side and confirmed that, from this side, one could clearly see through it. When the participant returned to his/her own side of the table, the model cautiously and quickly replaced the transparent sheet again with the opaque sheet. The P−/M− condition was conducted by shutting the LC-window off and showing the participant that, in this condition, neither the participant nor the model was able to see through the window during a trial. The presentation order of the conditions was counterbalanced across the participants. Participants were informed about all these conditions before starting the experiment. To control for the suspicion of deceit, participants were asked after the experiment about possible differences in their experiences between the stimulus presentation conditions. During the final debriefing, the deceit was unveiled and participants were asked directly if they had any doubts about the model not seeing them during the P−/M+ block. A participant was excluded from analyses if he/she expressed doubts regarding the deceit.

Within each block, two series of measurements were conducted. The first series was intended for the measurements of the SCRs and HR deceleration responses and it consisted of 10 trials. The stimulus duration was 5 s with an inter-stimulus interval (ISI) varying between 20 and 45 s. A new trial was allowed after recovery from the previous SCR. After the first five trials, a short break (1–2 min) was allowed.

The second series of measurements was to collect data for the ERPs and it consisted of 100 trials. The duration of stimulus presentation was 0.5 s with an ISI of 1.5 s. The stimuli were presented in 10-trial sequences. After each sequence, there was a 15-s break. After the first five sequences, participants were allowed a break of 1–2 min. ISIs consisted of those moments, when the LC window was not transparent (there was no buzzing sound). After each block, participants completed a self-assessment questionnaire. The participants were asked to fill the nine-item Situational Self-Awareness Scale (SSAS) (Govern and Marsch, 2001). The SSAS measures three different forms of self-awareness: public self-awareness (e.g. 'Right now, I am concerned about the way I present myself'), private self-awareness (e.g. 'Right now, I am conscious about my inner feelings') and awareness of one's immediate surroundings (e.g. 'Right now, I am keenly aware of everything in my environment'). The form used a 7-point scale. Participants were instructed to answer the questionnaire based on their feelings during the previous experimental block, not how they felt in general or at that point in their lives.

Acquisition of the physiological data

For the skin conductance measurements, two electrodes (Ag/AgCl) were attached to the palmar surface of the distal phalanxes of the index and middle fingers of the participant's left hand. For the HR measures, two electrodes (Ag/AgCl) were placed on both arms. The sampling rate for the digitized signals was 1000 Hz.

Continuous EEG was recorded from 64 sites using actiCAP active electrodes, and the signal was amplified with a quickAmp amplifier (Brain products GmbH, Munich, Germany). An average reference was used. The sampling rate for the digitized signal was set to 1000 Hz. Additionally, vertical (VEOG) eye movements were recorded above and below the left eye. Skin abrasion and electrode paste were used to reduce electrode impedances below 25 kΩ. All physiological data collection was controlled with Brain Vision Professional Recorder (Brain products GmbH, Munich, Germany) running on a PC computer.

Data analysis

The SCR data were re-sampled offline to 100 Hz and filtered with a 10 Hz low-pass filter. No high-pass filtering was used. The SCR was defined as the 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. In case there was more than 0.1 μs amplitude rise during the first second after stimulus onset, the trial was rejected. In this case, the response was too early to have been elicited by the stimulus. Of all trials, 6.0% were eliminated due to this criterion or because of technical errors. The data were averaged for each condition for each participant, including those trials with zero response. This method of calculation is referred to as the magnitude of galvanic skin response (Dawson *et al.*, 2000).

Electrocardiogram (EKG) was analysed offline with an in-house (MATLAB-based) algorithm to measure the time intervals between two successive R-waves (interbeat interval, IBI). After computer-based detection of R-peaks, the data were manually checked and corrected in cases of falsely detected or missing peaks. Trials with excessive distortion in the signal were excluded from the analysis (1.9% of the trials). For a period between 5 s pre-stimulus and 5 s post-stimulus within each trial, the IBIs were quantified and assigned to 1-s intervals. This was done by averaging the IBIs in each interval weighted by the proportion of the interval occupied by that beat. Lastly, IBIs were converted to beats per minute (bpm) and averaged across trials within each condition. A baseline was defined as the average of the IBIs during the 5-s pre-stimulus period. The analyses were conducted on HR-change scores that were calculated by subtracting the bpm of each post-stimulus 1-s interval from baseline. Thus negative change-score values indicated HR deceleration and positive values HR acceleration.

The continuous EEG-signal was offline-filtered with 0.5–30 band-pass filter with 24 dB/oct slope on both ends. The filtered signal was ocular-corrected using Gratton/Coles algorithm and manually checked for artefacts. Trials containing artefacts were rejected (4.0% of the trials). In order to study the ERP-responses, the signal was segmented into 600-ms long epochs starting 100 ms before stimulus onset and computed for each condition. The baseline was computed from the 100-ms pre-stimulus period. For the P3-component, we analysed the right and left anterior frontal and frontal pole regions [averaged over electrodes AF4, AF8 and Fp2 (right side), and AF3, AF7 and Fp1 (left side)], measuring the mean amplitude between 200 and 450 ms post-stimulus for each participant in each condition.

All statistical analyses were conducted using repeated-measures analyses of variance (ANOVA). Planned comparisons were performed for analyses of simple main effects when interactions were observed. A Greenhouse-Geisser correction was applied when appropriate. When needed, data were normalized using natural-log transformations. All analyses were conducted on normally distributed variables.

Results

Situational self-awareness

A one-way ANOVA of experimental condition was performed on the ratings on each dimension of self-awareness (public, private and awareness of surroundings). A significant effect was found for public self-awareness ($F_{2,48} = 5.98$, $P < 0.01$, $\eta^2_p = 0.20$) but not for the other dimensions ($Ps > 0.4$). Public self-awareness was greater both when the participant and the model could see each other ($t_{24} = 4.38$, $P < 0.01$, $d = 0.88$) and when the participant did not see the model but believed that the model could see him/her ($t_{24} = 1.07$, $P = 0.049$, $d = 0.42$) compared with when neither could see each other. Public self-awareness did not differ significantly between when the participant and the model could see each other and when the participant did not see the model but believed that the model could see him/her ($t_{24} = 0.92$, $P = 0.37$, $d = 0.18$). Thus, self-evaluated public self-awareness was enhanced independent of whether the participant saw the model as long as he/she believed themselves to be observed by the model. The self-awareness scores are presented in Table 1.

Table 1. Scores on the SSAS for the three experimental conditions

Self-awareness	P+/M+		P−/M+		P−/M−	
	M	s.d.	M	s.d.	M	s.d.
Private	4.05	1.12	4.31	1.17	4.31	1.19
Public	3.04	1.61	2.81	1.58	2.21	1.37
Surroundings	4.27	1.37	4.10	1.54	4.49	1.16

SSAS scores include private self-awareness, public self-awareness, and awareness of one's surroundings. The SSAS has a range of 1–7. P+/M+ = the participant and the model could both see each other; P−/M+ = the participant could not see the model, but believes that the model could see him/her; P−/M− = neither the participant nor the model could see each other.

Skin conductance

An ANOVA indicated a significant effect of experimental condition on SCR ($F_{2,34} = 14.99$, $P < 0.01$, $\eta^2_p = 0.47$). *T*-tests revealed that when the model and the participant could see each other SCRs were greater compared with when the participant did not see the model but believed that the model could see him/her ($t_{17} = 4.18$, $P < 0.01$, $d = 0.98$) or when the model and participant could not see each other ($t_{17} = 4.25$, $P < 0.01$, $d = 1.00$). Importantly, there were no differences in SCR between the two conditions where the model was not visible ($t_{17} = 0.51$, $P = 0.62$, $d = 0.12$). Mean SCR are shown in Figure 1.

Heart rate

A 5 × 3 ANOVA (time × experimental condition) on heart rate response revealed a main effect of time ($F_{4,72} = 5.23$, $P < 0.01$, $\eta^2_p = 0.23$) and a significant interaction between time and experimental condition ($F_{8,144} = 3.97$, $P < 0.01$, $\eta^2_p = 0.18$). We used t-tests to compare the maximal HR-decelerations between experimental conditions. The HR-deceleration was stronger when the participant and the model could see each other compared with when the participant did not see the model but believed that the model could see him/her ($t_{18} = 2.81$, $P = 0.01$, $d = 0.64$), and when the model or participant could not see each other ($t_{18} = 2.64$, $P = 0.01$, $d = 0.61$). Again, there were no differences in responses between the two conditions where the model was not visible ($t_{18} = 0.21$, $P = 0.83$, $d = 0.04$). Heart rate deceleration responses are shown in Figure 2.

P3 response

There was an expected modulation of the ERP responses whereby the presence of the visual stimulus induced a prominent negative shift in the waveform for the condition where the participant was able to see the model. For the P3 response, a 3 × 2 ANOVA (experimental condition × hemisphere) showed a main effect of experimental condition ($F_{2,36} = 61.91$, $P < 0.01$, $\eta^2_p = 0.78$) reflecting this negative shift. Importantly, however, there were no differences in the P3 responses between the two conditions where the model was not visible ($t_{18} = 0.03$, $P = 0.97$, $d < 0.01$), averaged across both left and right hemispheres. Thus, compatible with the skin conductance and heart rate deceleration responses, the P3 response was not larger when the participant did not see the model but still believed that the model could see him/her compared with when neither could see each other. The ERP responses are shown in Figure 3.

Discussion

In this study, we explored whether the mere belief of being seen by another person, without actually seeing the person, is enough to elicit similar self-awareness and physiological responses indexing arousal and attention allocation that typically follow making eye contact with another person. The self-assessed situational public self-awareness was higher when participants believed that they were being seen by the model compared with when not being seen, even when the model was not visible to the participant. When participants believed that they were being observed, they responded similarly regardless of whether they saw the observer or not. This result is consistent with our hypothesis, and not surprising given that Govern and Marsch (2001) described public awareness as a tendency to attend to the aspects of the self that are on public display. Public self-awareness is also associated with the feeling of being

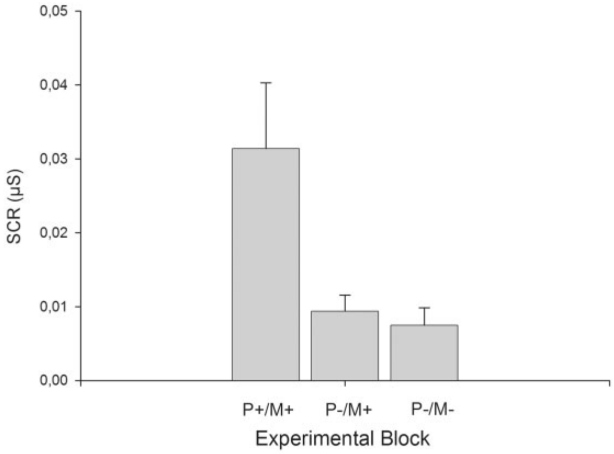

Fig. 1. SCR (mean + s.e.m.) in the three different experimental conditions. P+/M+ = the participant and the model could both see each other; P−/M+ = the participant could not see the model, but believes that the model could see him/her; P−/M− = neither the participant nor the model could see each other.

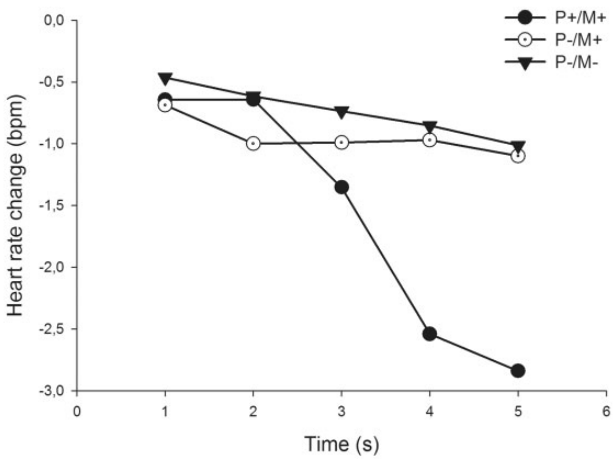

Fig. 2. Heart rate changes in the three different experimental conditions. P+/M+ = the participant and the model could both see each other; P−/M+ = the participant could not see the model, but believes that the model could see him/her; P−/M− = neither the participant nor the model could see each other.

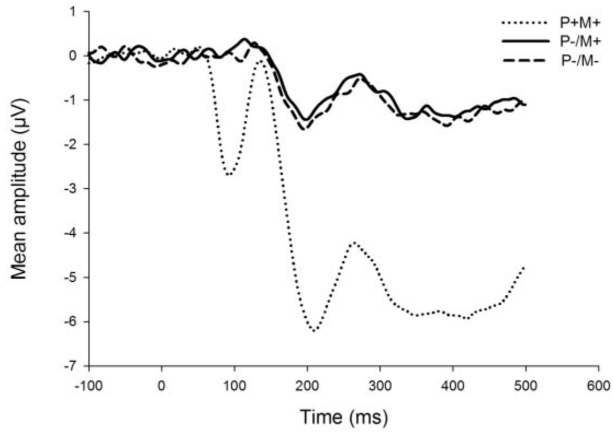

Fig. 3. Mean waveforms from frontal electrode sites in the three different experimental conditions. The presented waveforms are averaged over the left and right hemispheres. The timeframe of the P3 response is 200–450 ms. P+/M+ = the participant and the model could both see each other; P−/M+ = the participant could not see the model, but believes that the model could see him/her; P−/M− = neither the participant nor the model could see each other.

evaluated by another person (Buss, 1980). In our previous study (Myllyneva and Hietanen, 2015), we showed that public self-awareness decreased when participants were led to believe that they were not being observed by another person even when their own ability to see the other person was not affected. Thus, for public self-awareness, the crucial factor seems to be the knowledge of being seen by another person. The visibility of this observer does not have an effect on this subjective experience.

The results from our physiological measurements clearly differed from the results of the public self-awareness ratings. Against our hypothesis, one's belief of being seen by a nonvisible model had no effect on any of the measured physiological responses: SCR, HR and the P3 ERP component. The findings of our previous study (Myllyneva and Hietanen, 2015) showed that when participants believed they were being seen, autonomic activation was enhanced independent of whether they saw the observer's eyes or not. Instead, this study convincingly shows that the mental state of believing oneself to be observed by another person is not enough to elicit the enhanced physiological arousal and attention allocation. Together with our previous study, the present experiment strongly indicates that to elicit greater physiological arousal, the experience of being observed by another person must be accompanied by sensory evidence of this person.

One may question whether our manipulation really worked and whether the participants were convinced that they were being seen by the model even when they did not see the model themselves. Participants were interviewed after the experiment, and not a single participant expressed strong doubts regarding the deceit before being informed of the experiment. However, five participants did express doubts of deceit after the deception was unveiled. We re-analysed the data leaving out these participants, and still there was no sign of differential physiological responses to being seen *vs* not being seen when the model was not visible. Additionally, the results from the public self-awareness ratings strongly indicate that our experimental manipulation worked as intended. It is difficult to account for the stronger public self-awareness when the participants believe they are being observed by the hidden model if our manipulation did not work properly.

Many studies show that the autonomic nervous system can be activated without a sensory stimulus, e.g. with emotional or motor imagery (Lang, 1979; Guillot and Collet, 2005; Kreibig, 2010). However, our results show that the mere belief of being looked at by another individual is not enough to increase autonomic activation without any sensory (visual) information of this observer. This result calls for a revision of our previous suggestion that the belief that one is being watched is the pivotal factor behind the enhanced autonomic and brain responses during eye contact (Myllyneva and Hietanen, 2015). In light of the present evidence, it appears that there are actually two requirements which must be met: (i) having the experience of being looked at by another individual and (ii) having the experience of looking at the other individual. Only in this kind of condition is there a possibility for mutual social influence; without the experience of being looked at by another individual, one may merely be a passive observer, comparable to a television viewer, without the possibility to impact another individual. Without the simultaneous experience of looking at the other

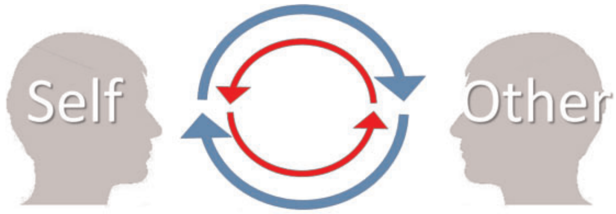

Fig. 4. An illustration describing mutual, visual interaction between two persons: the 'self' and the 'other'. Blue arrows depict an individual's experience of seeing the other person. Red arrows depict an individual's simultaneous experience of being influenced by the other person's behaviour. If one is not able to see the other (e.g. as in this study) or if the other is not able to see the self (e.g. Myllyneva and Hietanen, 2015) the upper or lower half, respectively, of this 'circle of interaction' breaks down, preventing mutual (visual) interaction. This model can also be applied to interactions involving other sensory modalities.

individual, one is essentially locked in an observation room with a one-way mirror without any chance to be impacted by the other individual's behaviour (Figure 4). This model is the most parsimonious explanation of the results from our previous and the present study. The function of the sympathetic nervous system is to prepare the body for action. Our results show that the presence of another person activates this system only to direct sensory stimuli in a condition where mutual interaction is possible. In contrast, public self-awareness is an internal mental state and can be heightened just by the belief that one is being looked at by another individual.

Our model is consistent with a recent account by De Jaegher *et al.* (2010) proposing that interaction includes at least two agents co-regulating and mutually affecting each other while preserving their individual autonomy. In fact, De Jaegher *et al.* (2010) explicitly suggest that the belief of another person's presence is not enough to constitute genuine social interaction. In a recent seminal review, Schilbach *et al.* (2013) use a term 'spectatorial gap' to describe a situation where a person is merely observing his/her surroundings without any possibility to interact with it. They suggest that when a possibility for interaction and/or emotional engagement is prevented social cognition may be fundamentally different compared with a natural encounter with another person. Our previous and present results are well in line with these considerations and provide empirical evidence for them. Our results show that closing or not closing this spectatorial gap can, indeed, have a major effect on attention and affective arousal-related autonomic and brain responses.

During the past decade, there has been active conversation about the importance of using real social stimuli and real social situations in social neuroscience and social cognition research (Hietanen *et al.*, 2008; Hari and Kujala, 2009; Risko *et al.*, 2012; Teufel *et al.*, 2012; Schilbach *et al.*, 2013). Many novel methods have been developed to overcome the difficulties of researching social phenomena during true interactions (Teufel *et al.*, 2009; Wilms *et al.*, 2010; Konvalinka and Roepstorff, 2012; Schilbach, 2014). Our method of using a liquid crystal window between two people and manipulating the participant's mental state while recording physiological responses offers one functional solution for creating experiments with a second-person approach. The present results show that the potential for genuine, mutual interaction can be a pivotal factor modulating arousal and attention-related responses. In future studies it would be interesting to explore which types of visual information may be enough (e.g. parts of the body or a silhouette) to elicit physiological responses similar to those when seeing the other person completely, and whether information via sensory modalities other than vision could be used to establish a similar mutual social contact resulting in enhanced physiological responses. This knowledge would be interesting not only from the perspective of social perception, but could also be relevant for social media and video communication technology.

Acknowledgements

This work was supported by the Academy of Finland (project no. 266187 to J.K.H.).

Conflict of interest. None declared.

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Biological Psychology 109 (2015) 151–158

Contents lists available at ScienceDirect

Biological Psychology

journal homepage: www.elsevier.com/locate/biopsycho

Psychophysiological responses to eye contact in adolescents with social anxiety disorder

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ARTICLE INFO

Article history:
Received 19 November 2014
Received in revised form 26 May 2015
Accepted 27 May 2015
Available online 29 May 2015

Keywords:
Social phobia
Skin conductance
Electroencephalography
Face perception
Social cognition

ABSTRACT

We investigated whether eye contact is aversive and negatively arousing for adolescents with social anxiety disorder (SAD). Participants were 17 adolescents with clinically diagnosed SAD and 17 age- and sex-matched controls. While participants viewed the stimuli, a real person with either direct gaze (eye contact), averted gaze, or closed eyes, we measured autonomic arousal (skin conductance responses) and electroencephalographic indices of approach–avoidance–motivation. Additionally, preferred viewing times, self-assessed arousal, valence, and situational self-awareness were measured. We found indications of enhanced autonomic and self-evaluated arousal, attenuated relative left-sided frontal cortical activity (associated with approach–motivation), and more negatively valenced self-evaluated feelings in adolescents with SAD compared to controls when viewing a face making eye contact. The behavioral measures and self-assessments were consistent with the physiological results. The results provide multifaceted evidence that eye contact with another person is an aversive and highly arousing situation for adolescents with SAD.

1. Introduction

Social anxiety is commonly defined as feelings of uneasiness arising when an individual interacts with others and anticipates the possibility of being negatively evaluated. The criteria for a clinical form of social anxiety, social anxiety disorder (SAD), are met when anxiety related to social situations interferes significantly with the person's normal life (American Psychiatric Association, 2013). The lifetime prevalence of SAD is estimated to be 7–13% (Furmark, 2002) and it typically emerges between early and late adolescence, the mean age of onset being between 10 and 16 years (Wittchen & Fehm, 2001). Cognitive-behavioral models of social anxiety suggest that negative self-appraisals in social situations are essential in the development and maintenance of social anxiety (Clark & Wells, 1995; Rapee & Heimberg, 1997). It has been proposed that social anxiety is associated with approach–avoidance conflicts resulting, on one hand, from increased investment in peer relationships in adolescence and, on the other hand, from a fear of humiliation and embarrassment aroused by peer evaluation (Caouette & Guyer, 2014).

Eyes are considered to be the strongest fear-producing cue in situations containing social appraisal (Öhman, 1986). An eye contact is a prominent way to signal preparedness for social interaction. A direct gaze signals that one's attention is directed towards the other person and an averted gaze suggests that one's attention is directed to someplace else. Thus, a direct gaze may be a potential threat for people with social anxiety. A prominent clinical symptom of SAD is avoidance of eye contact as well as other safety behaviors in social situations (Greist, 1994).

Previous research has shown shortened viewing times of the eye region or reduced eye contact in participants with social anxiety in comparison to non-anxious participants (Daly, 1978; Farabee, Holcom, Ramsey, & Cole, 1993; Garner, Mogg, & Bradley, 2006; Moukheiber et al., 2010). However, some studies have not found differences in gazing behavior between participants with and without social anxiety (Hofmann, Gerlach, Wender, & Roth, 1997), and even longer fixation times to the eye region by socially anxious females compared to non-anxious counterparts have been reported (Wieser, Pauli, Alpers, & Mühlberger, 2009). These discrepancies have been partly explained with a hypervigilance-avoidance hypothesis proposing that anxious individuals initially attend to but subsequently avoid threatening stimuli (Wieser, Pauli, Weyers, Alpers, & Mühlberger, 2009). It is also noteworthy, that only two of the studies cited above investigated clinically diagnosed socially anxious participants (Moukheiber et al., 2010; Hofmann et al.,

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http://dx.doi.org/10.1016/j.biopsycho.2015.05.005
0301-0511/© 2015 Published by Elsevier B.V.

1997). Studies reporting physiological responses to eye contact in adults or adolescents with social anxiety are scarce. Wieser, Pauli, Alpers, et al. (2009) found more pronounced cardiac acceleration, an index of autonomic reactivity, in participants scoring high in social anxiety to direct vs. averted gaze, whereas this difference was reversed in the group with medium scores and it was non-existing in low socially anxious group. However, measurements of skin conductance responses, another measure of autonomic arousal shown to be sensitive to gaze direction in several studies (Helminen et al., 2011Helminen, Kaasinen, & Hietanen, 2011; Hietanen, Leppänen, Peltola, Linna-aho, & Ruuhiala, 2008; Nichols & Champness, 1971; Pönkänen et al., 2011b; Myllyneva & Hietanen, 2015), did not indicate differences in responses to direct versus averted gaze in any of the groups.

Previous research has thus provided some evidence suggesting that seeing another person's direct gaze may be an aversive and arousing stimulus for individuals suffering from social anxiety. In the present study, we aimed at providing further evidence for the aversive and arousing nature of direct gaze for socially anxious individuals and, more specifically, we aimed to investigate whether this is reflected in the psychophysiological measurements of cortical and autonomic nervous system activity. Electroencephalographic (EEG) studies have associated approach–avoidance–motivation to asymmetries in the frontal alpha activity (8–13 Hz). Stronger left-sided vs. right-sided frontal activity has been associated with activations of the approach–motivation system, whereas stronger right-sided vs. left sided activity has been associated with the activation of the avoidance–motivation system (Davidson, 2004; Harmon-Jones, 2003; Van Honk & Schutter, 2006). Now there is experimental evidence showing that, in healthy adults, seeing a face with a direct vs. averted gaze results in more pronounced left-sided, approach-related frontal EEG activity in the perceiver's brain (Hietanen et al., 2008; Pönkänen et al., 2011b). Interestingly, stronger relative left-sided activity to direct vs. closed eyes has been observed also in typically developing children, but not in children with autism spectrum disorder (Kylliäinen et al., 2012). Although there are no previous studies measuring asymmetries in the frontal alpha activity of people suffering from social anxiety in response to perceiving a face with different gaze directions, individuals with social anxiety have been shown to exhibit elevations in right-sided, avoidance-related frontal EEG activity during resting state measurements under social stress (Davidson, Marshall, Tomarken, & Henriques, 2000). However, the findings concerning frontal alpha asymmetry in anxiety disorders are not totally consistent (for a review, see Thibodeau, Jorgensen, & Kim, 2006). One possible reason for these inconsistencies may be that passive resting state measurements are not optimal to capture state or trait relevant EEG-asymmetries and that emotionally and motivationally relevant situations should be employed instead (e.g., Coan, Allen, & McKnight, 2006; Wacker, Chavanon, & Stemmler, 2010).

In earlier studies from our laboratory, we have shown that viewing a face of a real live person, physically present in the experimental situation, elicits differential physiological and self-assessed responses compared to viewing a picture of a face (Hietanen et al., 2008; Pönkänen, Peltola et al., 2011; Pönkänen, Alhoniemi, Leppänen, & Hietanen, 2011). For example, pronounced left-sided, approach-related frontal EEG activity and enhanced skin conductance responses to direct versus averted gaze were observed in response to live faces, but not when the faces of the same persons were shown in a pictorial format. The differences were suggested to be due to mentalizing processes, following from being looked at by another person (Hietanen et al., 2008; Myllyneva & Hietanen, 2015; Pönkänen, Peltola et al., 2011). Being looked at by another individual is likely to elicit feelings of being evaluated. These feelings are, in turn, associated to public self-awareness (Buss, 1980). Our previous studies have shown, indeed, that self-assessed public self-awareness is higher when being looked at by a real person versus not being looked at (Hietanen et al., 2008; Pönkänen et al., 2011b; Myllyneva & Hietanen, 2015). Cognitive theories of SAD postulate that heightened public self-awareness plays a central role in social anxiety (Clark & Wells, 1995; Rapee & Heimberg, 1997) and this is supported by empirical evidence (Hope & Heimberg, 1988; George & Stopa, 2008). Against these previous findings, we reasoned that the use of live social stimuli with a potential for interaction is especially important when investigating participants with social anxiety suffering from fear of negative evaluation and criticism from other people. Several other researchers working in the field of social cognition and social neuroscience have also raised similar concerns regarding the ecological validity of facial stimuli presented in pictorial or video format (Risko, Laidlaw, Freeth, Foulsham, & Kingstone, 2012; Schilbach et al., 2013; Teufel et al., 2012). In the above mentioned studies investigating socially anxious individuals' gazing of the eye region, only three had participants viewing real persons instead of pictures or videos (Daly, 1978; Farabee et al., 1993; Hofmann et al., 1997), and yet the difference between using real persons vs. pictures or videos as stimuli can be considerable on gazing behavior (Laidlaw, Foulsham, Kuhn, & Kingstone, 2011).

In the present study, we investigated autonomic arousal and approach–avoidance related brain activity in response to a face with different gaze directions in adolescents with clinically diagnosed SAD vs. age and sex matched controls. We showed the participants a live face with either direct gaze, averted gaze, or closed eyes through a liquid crystal window, and simultaneously recorded skin conductance responses (SCR) and electroencephalographic (EEG) cortical activity. We hypothesized that all participants would show heightened sympathetic activity and, thus, larger SCRs to direct gaze compared to averted gaze or closed eyes. Because anxiety and fear are related to heightened autonomic activation (Kreibig, 2010), we expected that this pronounced sympathetic activation to direct gaze would be more salient in the SAD group than in the control group. Secondly, we hypothesized that participants in the SAD group would show less relative left-sided frontal cortical activity specifically when observing a face with a direct gaze compared to participants in the control group. In the second part of the experiment, the participants controlled the presentation of the stimuli (a face with a direct or averted gaze) themselves, and in addition to the psychophysiological responses, we measured the viewing time of the facial stimuli. We expected shorter self-controlled viewing times for direct gaze in the SAD group than in the control group. Finally, the participants were also asked to assess their subjective arousal, valence, and situational self-awareness when viewing a face with a direct or averted gaze. We expected that participants in the SAD group would show higher ratings of self-assessed arousal, lower ratings of affective valence (pleasantness), and higher levels of self-assessed public self-awareness for direct gaze compared to participants in the control group.

2. Methods

2.1. Participants

The participants were seventeen adolescents with SAD (mean age 15.2 years, std 1.52, range 13–17) and seventeen age- and gender-matched controls (mean age 15.3 years, std 1.53, range 13–17). Both groups consisted of 4 males and 13 females. The control group was composed in such a way that each socially anxious participant had a gender-matched counterpart differing less than six months in age. Adolescents with SAD were recruited from the Department of Adolescent Psychiatry, Tampere University Hospital. Participants were included in the clinical group if their primary reason for referral was social anxiety and they fulfilled DSM-IV criteria for SAD. The diagnosis was based on a clinical interview K-SADS-PL (Schedule for Affective Disorders and Schizophrenia for School-Age Children-Present and Lifetime version; Kaufman et al., 1997), which has shown validity for identifying anxiety disorders in adolescents. Comorbidity with K-SADS-PL affective and anxiety disorders was allowed. The participants did not have neurological or medical diseases and did not have regular medication.

The control participants were recruited from local upper comprehensive and high schools. The controls were first screened with the Social Phobia Inventory (SPIN) (Connor et al., 2000), an instrument possessing good screening properties for SAD in the Finnish adolescent population (Ranta, Kaltiala-Heino, Rantanen, Tuomisto, & Marttunen, 2007), and invited to an interview if the total score was 0–9 representing low levels of social anxiety. All the clinical participants had SPIN scores higher than 20. Finally, the controls were also interviewed clinically with the K-SADS-PL by adolescent psychiatrist. Only those without SAD, and without any other anxiety/affective or other K-SADS-PL based Axis I disorders were included in the control group. All participants gained 2 movie tickets for participation. Laboratory measurements of one socially anxious participant were aborted after the first part due to headache. Consequently, the data of the first part of the experiment consist of 17 clinical and 17 control participants, and the data of consecutive parts consist of 16 clinical and 17 control participants. Informed, written consent was obtained from all participants and their parents. Ethical statement for the study was obtained from the Ethical Committee of Pirkanmaa Hospital District.

2.2. Stimuli and the experimental procedure

The stimulus was a face of a person (model) gazing either directly at the participant, gazing 30° to the left or right, or having eyes closed. Three females, naïve to the purpose of the experiment and trained to act similarly towards the participants served as models. Each participant saw only one model. During the experiment, the models bore a neutral expression on their faces. The ages of the models' were 23, 24 and 24 years. Faces were presented through a 30×40 cm liquid crystal (LC) window (NSG UMU Products Co., Ltd.), attached to a black frame. The LC-window switched between the opaque and transparent state within milliseconds. The participants were seated at a distance of 60 cm from the LC-window and the overall distance to the model sitting on the other side was 120 cm.

The experiment consisted of three separate blocks. In the first block, the presentation of the stimuli was computer-controlled. The face of the model had a direct gaze, averted gaze or closed eyes. The first block consisted of 27 trials (nine trials in each gaze condition). The presentation order of the stimuli in the trial sequence was randomized. The stimulus duration was 5 s and the inter-stimulus interval (ISI) varied between 20 and 40 s. A new trial was initiated after recovery from previous skin conductance response. The participants were allowed two short breaks during the first block (after nine and eighteen trials). Stimulus presentation was controlled by Neuroscan Stim-software running on a desktop computer.

In the second block, participants controlled the presentation time themselves with a computer mouse and the face of the model had either a direct or averted gaze. The second block consisted of 20 trials (10 with direct gaze and 10 with averted gaze). The participants were instructed to use a computer mouse for opening and closing the LC-window. They heard a soft audio signal, after which they were able to open the window with one button and close it with another. For the controlling of the viewing time, the participant was instructed as follows: the time that different people find it natural to look at another person's face in different situation varies. You can choose your own looking time based on how you feel. 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 the instruction, it was not mentioned that it would have been possible for the participants not to open the window at all. No participant asked about this possibility nor left the window unopened. The presentation order of the stimuli in the trial sequence was randomized. A new trial was allowed 20 seconds after the ending of the previous one. In both blocks, during the ISI, the LC-window remained opaque. Along with the physiological measures, viewing times were recorded.

In the third block, the participants were asked to fill self-assessment forms. First they were asked to assess their arousal and affective valence to seeing a face with direct gaze, averted gaze, and closed eyes with 9-point scales of the Self-Assessment Manikin (SAM) (Bradley & Lang, 1994; 1 = unpleasant/calm, 9 = pleasant/arousing). The same face as previously with direct gaze, averted gaze or closed eyes was presented through the LC-window for 5 s in a random order. Lastly, the participants were introduced a nine-item Situational Self-Awareness Scale (SASS) form (Govern & Marsch, 2001) measuring public self-awareness (e.g., Right now, I am concerned about the way I present myself), private self-awareness (e.g., Right now, I am conscious of my inner feelings) and awareness of immediate surroundings (e.g., Right now, I am keenly aware of everything in my environment). Again, the same face as previously with a direct gaze and averted gaze was shown for the participant for 5 s in a random order. The participants were asked to fill the SSAS ratings after seeing each face. The form used 7-point scale (1 = strongly disagree, 7 = strongly agree). No task was required during the experiment, except to watch the face of the model when the LC-window is open.

2.3. Acquisition of the physiological data

For the skin conductance measurements, two electrodes (Ag/AgCl) 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. Power Lab 400 equipment running on a desktop computer was used to measure the skin conductance. The sampling rate was 100 Hz.

Continuous EEG was recorded from eight electrode sites (F3, F4, F7, F8, C3, C4, P3, P4) positioned according to 10–20 system. The signal was referenced to mathematically linked ears as recommended by Hagemann, Naumann, and Thayer (2001). Horizontal and vertical eye movements were recorded from the sites beside the outer canthi of each eye and above and below the left eye. Skin abrasion and electrode paste were used to reduce the electrode impedances below 5 kΩ. The EEG signal was amplified with SynAmps amplifiers with a gain of 5000. The signal was filtered using a 1–200 band-pass filter (50 Hz notch filter enabled). The sampling rate for the digitized signal was 1000 Hz.

2.4. Data analysis

The skin conductance response was defined as a maximal amplitude change from the baseline level during a 4-s time period starting after 1 s from the stimulus onset. If the maximum amplitude was negative, it was set to zero. If there was more than 0.1 μS amplitude change before 1 s after stimulus onset, the trial was rejected for being too early to be elicited by the gaze stimulus (Dawson, Schell, & Filion, 2000). Of all trials, 13.1% were rejected in the computer-controlled condition and 18.9% in the self-controlled condition because of these criteria or because of technical error. The data were averaged in each condition for each participant, including those trials with zero response. This method of calculation results in the magnitude of the galvanic skin conductance response (Dawson et al., 2000).

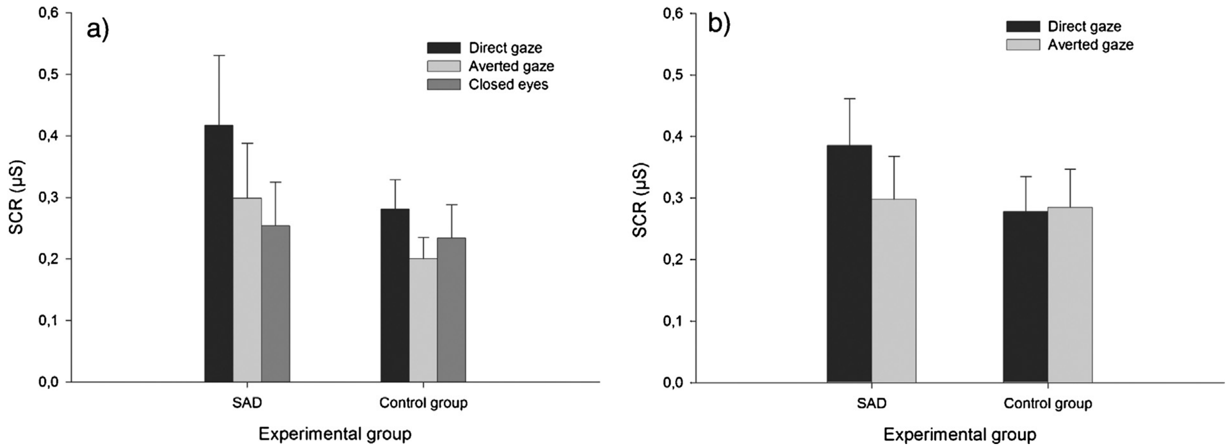

Fig. 1. Mean skin conductance responses to direct gaze, averted gaze and closed eyes (a) in computer-controlled viewing time condition and (b) in self-controlled viewing time condition

The EEG-signal was filtered with a 0.5–30 band-pass filter with 24 dB/oct slope on both end, and ocular-corrected using Gratton/Coles–algorithm. The signal was segmented into nine 1024 ms long epochs with 50% overlap between adjacent epochs starting from the stimulus onset. The epochs were manually checked for artifacts. Spectral power was calculated for each artifact-free epoch using fast Fourier transform (FFT) with a 25% Hanning window. The obtained power spectra were averaged over all artifact-free epochs within each trial and over separate trials within each experimental condition (direct gaze, averted gaze and eyes closed). Periods with less than 50% artifact-free epochs were excluded from the analysis. Power density values (μV^2/Hz) within the alpha-band (8–13) were calculated. Lastly, alpha-asymmetry [Ln (PowerDensity F4) – Ln (PowerDensity F3)] scores were calculated.

The self-controlled viewing times were recorded in the second experimental condition. The viewing time–data were averaged in both gaze-conditions for each participant.

In statistical analyses, Greenhouse–Geisser correction procedure was applied when appropriate. Planned comparisons (two-tailed) were performed for the analysis of simple main effects when interactions were observed. When needed, data were normalized using ln-transformation. Due to artifacts, there was a substantial (9.3%) number of missing values in the EEG power density dataset for the facial stimuli scattered randomly to the data. For maximal utilization of the available data, we used mean imputation to replace the missing values. As means, we used the arithmetic means of variables over both experimental groups. In SCR and viewing time data, there were no values differing more than 1.5 interquartile lengths from the first and third quartiles. For frontal asymmetry data, we included values differing less than 3 interquartile lengths from Q1 or Q3. This lead to exclusion of one control participant from the analysis

3. Results

3.1. Skin conductance response

For the computer-controlled presentations, a 3 × 2 ANOVA was conducted with gaze direction (direct, averted, eyes closed) as a within-subjects factor and group (clinical, control) as a between-subjects factor. A main effect of gaze direction was revealed($F_{(2,60)} = 4.4$, $p = 0.026$, $\eta_p^2 = 0.129$) indicating larger responses to direct gaze compared to averted gaze or closed eyes regardless of experimental group. Other effects remained non-significant. Mean SCRs for each gaze direction are presented in Fig. 1a.

For the self-controlled presentations, a 2 × 2 ANOVA was conducted with gaze direction (direct, averted) as a within-groups factor and group as a between-subjects factor. A main effect of gaze direction was marginally significant ($F_{(1,31)} = 3.5$, $p = 0.07$, $\eta_p^2 = 0.102$). More importantly, however, there was an interaction between gaze direction and group ($F_{(1,31)} = 4.4$, $p = 0.043$, $\eta_p^2 = 0.125$). When comparing the responses to direct and averted gaze between groups, *t*-tests did not find any significant effects (all ps < 0.1). Further analysis revealed that interaction was due to differences in responses to direct and averted gaze within groups: *t*-tests indicated greater response to direct gaze than to averted gaze in the clinical group ($t = 2.5$, $p = 0.023$, df = 15, $d = 0.63$) but not in the control group ($t = 0.18$, $p = 0.86$, df = 16, $d = 0.04$). Mean SCRs for each gaze direction and for both groups are presented in Fig. 1b.

3.2. Frontal EEG asymmetry to facial stimuli

Fig. 2 presents mean frontal alpha-asymmetry scores for both experimental groups in the computer-controlled stimulus presentation condition. A 3 × 2 ANOVA revealed no main effects, but there was a marginally significant interaction between gaze direction and

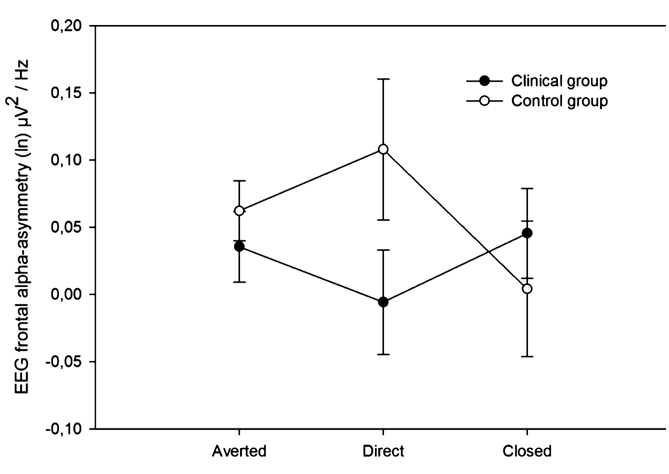

Fig. 2. Mean frontal alpha-asymmetry scores to direct gaze, averted gaze and closed eyes. A positive value indexes stronger relative left-sided frontal brain activity associated with approach–motivation and a negative value indexes stronger relative right-sided frontal brain activity associated with avoidance–motivation.

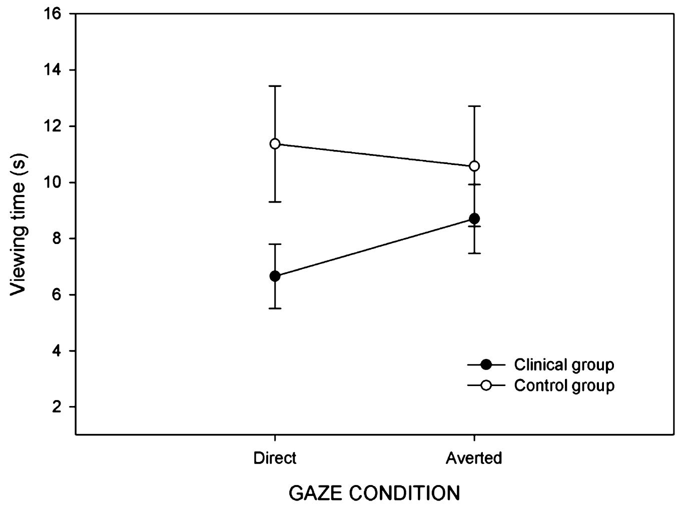

Fig. 3. Mean preferred viewing times to direct gaze and averted gaze facial stimuli in self-controlled viewing time condition.

group ($F_{(1,30)} = 2.66$, $p = 0.078$, $\eta_p^2 = 0.08$). A *t*-test for independent samples suggested that alpha-asymmetry scores for seeing a face with direct gaze was marginally more positive in the control group compared to the clinical group ($t = 1.73$, $p = 0.094$, df = 30, $d = 0.53$).

3.3. Viewing time

Fig. 3 shows mean viewing times in the self-controlled presentation block for direct and averted gaze in both experimental groups. A 2 × 2 ANOVA revealed a main effect of gaze direction ($F_{(1,31)} = 5.5$, $p = 0.026$, $\eta_p^2 = 0.15$) and an interaction between gaze direction and group ($F_{(1,31)} = 12.8$, $p = 0.001$, $\eta_p^2 = 0.29$). For direct gaze, an independent-samples *t*-test indicated shorter viewing times in the clinical group compared to the control group ($t = 2.27$, $p = 0.03$, df = 31, $d = 0.77$). For averted gaze, there was no difference between the groups ($t = 0.62$, $p = 0.54$, df = 31, $d = 0.21$).

3.4. Self-assessed arousal and valence

The subjective ratings of arousal and valence are shown in Table 1. A 3 × 2 ANOVA for self-ratings of arousal revealed a main effect of gaze direction ($F_{(2,60)} = 32.9$, $p < 0.001$, $\eta_p^2 = 0.523$) and an interaction between gaze direction and group ($F_{(2,60)} = 4.7$, $p = 0.013$, $\eta_p^2 = 0.135$). For direct gaze, a *t*-test showed higher arousal ratings in the clinical group compared to the control group ($t = 2.52$, $p = 0.02$, df = 30, $d = 0.80$), whereas the difference was not significant between the groups for averted gaze ($t = 0.78$, $p = 0.44$, df = 31, $d = 0.25$) or for closed eyes ($t = 1.51$, $p = 0.14$, df = 30, $d = 0.52$).

A 3 × 2 ANOVA for valence ratings indicated significant main effects of gaze direction ($F_{(2,60)} = 16.9$, $p < 0.001$, $\eta_p^2 = 0.361$) and group ($F_{(1,30)} = 7.2$, $p = 0.011$, $\eta_p^2 = 0.196$). Overall, the pleasantness ratings were the lowest for direct gaze and the highest for closed eyes; participants in the control group gave higher pleasantness ratings than participants in the clinical group. Importantly, the interaction between gaze direction and group was significant ($F_{(2,60)} = 6.2$, $p = 0.004$, $\eta_p^2 = 0.170$). When analyzing the responses to different gaze directions separately between the clinical and control groups, *t*-tests indicated lower pleasantness ratings in the clinical vs. control group to direct gaze ($t = 3.81$, $p = 0.001$, df = 31, $d = 1.21$), marginally significantly to an averted gaze ($t = 1.76$, $p = 0.09$, df = 30, $d = 0.56$), and no difference in ratings to closed eyes ($t = 0.25$, $p = 0.80$, df = 31, $d = 0.33$). Importantly, participants in the control group evaluated direct gaze as mildly pleasant ($M = 5.43$), whereas the participants with SAD evaluated direct gaze as unpleasant ($M = 3.19$).

3.5. Self-awareness

Situational self-awareness was analyzed separately for each of three components (public, private and awareness of surroundings). For public self-awareness, a 2 × 2 ANOVA with gaze direction (direct, averted) as a within-subjects factor and group (clinical, control) as a between subjects factor revealed main effects of gaze direction ($F_{(1,31)} = 15.9$, $p < 0.001$, $\eta_p^2 = 0.339$) and group ($F_{(1,31)} = 10.3$, $p = 0.003$, $\eta_p^2 = 0.248$The self-assessed public self-awareness was higher to direct vs. averted gaze and, overall, it was higher in the clinical than in the control group. No effects were found for private self-awareness or awareness of immediate surroundings (all ps > 0.1). Mean SSAS scores for both groups are shown in Table 1.

4. Discussion

In the present study, we investigated adolescents with clinically diagnosed social anxiety disorder (SAD) and age- and sex-matched controls in their responses to seeing another person live with a direct gaze, averted gaze, and closed eyes. We investigated whether eye contact is aversive and physiologically arousing for adolescents with SAD by measuring autonomic skin conductance responses (SCR), cortical EEG activity measures (i.e., lateral asymmetry in frontal alpha activity) indexing behavioral approach–avoidance tendencies, as well as self-controlled viewing time of the stimulus faces. Additionally, we measured self-assessed arousal, valence, and situational self-awareness during looking at the stimulus face with different gaze directions.

Consistently with previous results using real persons as stimuli (Helminen et al., 2011; Hietanen et al., 2008; Myllyneva & Hietanen, 2015; Nichols & Champness, 1971; Pönkänen, Peltola et al., 2011), we found larger SCRs when seeing a face with direct gaze compared to seeing a face with averted gaze or closed eyes. Interestingly, however, in the self-controlled viewing block, this difference was observed only in adolescents with SAD. Thus, only the adolescents with SAD had larger SCRs to seeing a face with direct vs. averted gaze when having a control over the presentation onset and viewing time. There is experimental evidence that increases in the situational control can reduce people's stress and arousal (Miller, 1979). Thus, it may be that having the possibility to control the moment of stimulus presentation lowered the arousal response in the control group. However, our self-controlled stimulus presentation not only gave more control to the participants, but also forced them to be more active and initiate the visual interaction with the model. This may have resulted in additional stress and anxiety in the participants with SAD, specifically when perceiving a direct gaze, i.e., being looked at by another person. According to the cognitive-behavioral model of social anxiety, the primary threat in SAD is a possibility of being negatively evaluated by others because of one's own actions (Rapee & Heimberg, 1997). Thus, in a situation where one is active in the initiation of an interaction, one naturally exposes oneself more to others' evaluation compared to a situation where one is passive while being observed by another individual.

In the self-controlled experimental situation, it was possible to choose very short viewing times also. Is it possible that the observed SCR results, in this situation, were affected by differences in the viewing-times? We do not find this likely. First, if anything, shorter viewing times would be expected to result in smaller SCRs, but the results showed that the SCRs do direct gaze were larger in the clinical than in the control group even though the viewing-times were shorter in the clinical group. Secondly, previous studies have shown that a 2-s presentation of a real human face evokes similar

Table 1
The self-assessed situational self-awareness scores (and standard deviations) to direct gaze and averted gaze facial stimuli, and the self-assessed ratings of valence and arousal. The scores of SSAS include three factors of self-awareness: public, private and surroundings. The scale-range in SSAS scores is 1–7 and valence and arousal scores 1–9.

	Clinical group			Control group		
	Direct gaze	Averted gaze	Closed eyes	Direct gaze	Averted gaze	Closed eyes
Arousal	4.63 (2.03)	3.12 (1.69)	2.38 (1.20)	3.00 (1.59)	2.71 (1.45)	1.75 (1.13)
Valence	3.19 (1.94)	4.5 (1.67)	5.94 (1.43)	5.43 (1.59)	5.44 (1.31)	6.06 (1.34)
Public	4.74 (1.71)	3.68 (1.30)	–	2.90 (1.71)	2.35 (1.40)	–
Private	3.75 (1.38)	3.52 (1.23)	–	3.47 (1.18)	3.47 (1.09)	–
Surroundings	3.75 (1.20)	3.85 (0.98)	–	4.65 (1.57)	4.37 (1.70)	–

SCRs compared to a 5-s presentation (Helminen et al., 2011). In the present experiment, there were two participants who had viewing times shorter than 2-s in the self-controlled block for direct gaze stimuli. Both participants were from the clinical group, and the number of trials viewed less than 2s was relatively large (8/10 and 9/10). However, the mean SCR of these two participants to the direct gaze stimuli in the self-controlled block ($M = 0.37\ \mu S$) did not differ from the mean SCR of the rest of the clinical group ($M = 0.38\ \mu S$). Thus, we find it unlikely that the SCRs in the self-controlled block would have been affected by the differences in the stimulus viewing-times.

Our results showed weaker left-sided (approach-related) frontal EEG asymmetry among adolescents with SAD when viewing facial stimuli with direct gaze compared to the control participants. No differences were found in the frontal EEG asymmetry between the groups when seeing a face with averted gaze or closed eyes. The effect was only marginally significant but we think that the effect-size of the pairwise comparison was notable ($d = 0.53$). Considering that the left-sided frontal EEG asymmetry has been associated with the functioning of the approach motivational system (Davidson, 2004; Harmon-Jones, 2003; Van Honk & Schutter, 2006), the present results suggest that seeing another person with a direct gaze elicits less behavioral tendencies of approach in adolescents with SAD than in the control adolescents. These results fit well with the current cognitive theories linking social anxiety with avoidance in social situations (Clark & Wells, 1995; Rapee & Heimberg, 1997). The alpha-asymmetry results are also interesting considering the several behavioral studies showing shortened viewing times of the eye region or reduced eye contact in participants with versus without social anxiety (Daly, 1978; Farabee et al., 1993; Garner et al., 2006; Moukheiber et al., 2010). These results combined with ours suggest that, in SAD, facing another person looking back at the perceiver elicits frontal EEG asymmetry at the level of brain activation, and simultaneously a tendency to avoid eye contact at the behavioral level.

As expected, the participants with SAD viewed a face with direct gaze for shorter time than the controls, whereas this difference was not present when viewing a face with averted gaze. Our results are in line with the majority of previous studies reporting shortened viewing times to an eye area or reduced eye contact by participants with social anxiety (Daly, 1978; Farabee et al., 1993; Garner et al., 2006; Moukheiber et al., 2010). Admittedly, our measure is not directly linked to viewing behavior per se, but to preferred viewing time. Nevertheless, our results show that adolescents with SAD not only display reduced eye contact, but also choose such actions that result in shorter interaction times with a person who is in eye contact with them. This, again, is well in line with cognitive models of social anxiety (Clark & Wells, 1995; Rapee & Heimberg, 1997) and expands the previous behavioral results concerning social interaction in social anxiety.

Adolescents with SAD assessed their subjective level of arousal to be higher when seeing a face with a direct gaze compared to the controls. No differences between the groups were observed when viewing a face with averted gaze or closed eyes. Thus, self-reported arousal for a direct gaze stimulus differentiated between the SAD and control groups even without having control over viewing time. This result differs from those obtained from SCR-measurements, where the difference was observed only when the participants had control over the viewing time. However, it is likely that the SCRs and self-assessments of arousal measured slightly different things in the present study. As SCRs were measured during the viewing task, they were stimulus driven and arguably not much affected by conscious control processes. Self-assessed arousal ratings, on the other hand, were made after both viewing tasks (i.e., the computer- and self-controlled) and, moreover, they were likely to reflect, not only stimulus-driven responses, but also experience-based cognitive appraisal of situations when being looked at by another person. The self-assessed valence ratings provided an important addition to the arousal rating results. They showed that whereas in adolescents with SAD, increased arousal to a face with direct gaze was accompanied by a negatively valenced affect, among the non-anxious adolescents, instead, the increased arousal was accompanied by a positive affect. This result is highly consistent with frontal EEG asymmetry findings of the present experiment. It is also a very obvious factor explaining the self-controlled viewing time results. In several previous studies, eye contact with another live person has not only increased arousal but also public self-awareness (Hietanen et al., 2008; Myllyneva & Hietanen, 2015; Pönkänen, Peltola et al., 2011). Heightened public self-awareness is described in cognitive theories of SAD (Clark & Wells, 1995; Rapee & Heimberg, 1997) and reported in the previous studies (Hope & Heimberg, 1988; George & Stopa, 2008). In the present study, we found both of these effects: public self-awareness was higher to direct versus averted gaze and, overall, it was higher in the SAD than the control group.

Our sample size was rather small which might explain why some of the anticipated effects were not observed. For example, we did not observe differences in frontal asymmetry scores between direct and averted gaze for neither experimental group. Such an effect has been observed in our earlier studies with healthy adults (Hietanen et al., 2008; Pönkänen, Peltola et al., 2011). Additionally, our models were young adults and, therefore, did not belong to the same age group as our participants. It is well known that, in adolescence, the importance of peer relations and peer group acceptance are emphasized (e.g., La Greca & Lopez, 1998). The possibility of being negatively evaluated by an adult may be a smaller threat to a socially anxious adolescent than being negatively evaluated by a peer. This also potentially weakened the effect of the eye contact.

Due to a moderate sample size and unbalanced sex-distribution among our participants, we were not able to consider same-sex versus opposite-sex effects. There is a possibility that the responses to seeing another person are modulated by the sex of the observer and/or the sex of the observed person. For example, Pönkänen, Peltola et al. (2011) observed differential frontal EEG asymmetry responses between seeing a real person with direct versus averted gaze, but only when the stimulus person was a female. We re-analyzed our psychophysiological and viewing time data leaving out all male participants and observed virtually unchanged effect-sizes for SCR and viewing-time, but notably higher effect-sizes for frontal EEG asymmetry results (effect-sizes for all participants, $\eta_p^2 = 0.08$, $d = 0.53$; effect-sizes for females only, $\eta_p^2 = 0.13$, $d = 0.89$). In future studies, it would be worthwhile to systematically explore the sex-effects in responses to seeing another person, both in clinical and in normal populations.

In our experimental situation, participants were not informed about a possibility not to open the window at all and no participant did so. It is probable that some participants (particularly clinical participants) felt uneasiness and, at the same time, social pressure from experimenters towards opening the window. One could argue that this resulted in an unnatural situation and decreased the validity of our results. It is noteworthy, however, that, in many occasions in real life, interaction can be actively initiated but in some sense forced, at the same time. At the grocery store, for example, one may initiate an interaction (by going to a cashier) and yet may feel forced to be an active initiator regardless of whether he/she wants to interact or not (taken that the person wants to buy something). The anxiety stemming from the expectation of interaction in these sorts of situations is one of the core symptoms of SAD.

Recently it was shown that a key factor modulating physiological and self-assessed responses to eye contact is not the visual perception of direct gaze per se but the belief of being seen by another person (Myllyneva & Hietanen, 2015). Thus, the present study can be seen as providing more evidence to propositions that a core feature of SAD is negative cognitions and affect elicited by exposing oneself to other individuals' attention. Our results also demonstrate that by investigating responses to eye contact in a genuine, social situation, it is possible to reveal a highly consistent, multi-level pattern of results characterizing the core symptoms in SAD.

Conflict of interest

The authors declare no conflicts of interest

Aknowledgements

We thank Stefanie Scheid, Sari Oldèn and Leena-Kaisa Saarimaa for their help in collecting the data. This work was supported by the Academy of Finland (projects #131786 and #266187 to J.K.H.)

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