Neuroscience and Biobehavioral Reviews xxx (2013) xxx–xxx

Contents lists available at ScienceDirect

Neuroscience and Biobehavioral Reviews

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

Review

From gaze cueing to dual eye-tracking: Novel approaches to investigate the neural correlates of gaze in social interaction

Ulrich J. Pfeiffer[a,*], Kai Vogeley[a,b], Leonhard Schilbach[a]

[a] Neuroimaging Group, Department of Psychiatry, University Hospital Cologne, Kerpener Strasse 62, 50937 Cologne, Germany
[b] Institute of Neuroscience and Medicine-Cognitive Neuroscience (INM3), Research Center Juelich, Leo-Brandt Strasse, 52428 Juelich, Germany

ARTICLE INFO

Article history:
Received 10 April 2013
Received in revised form 16 July 2013
Accepted 26 July 2013

Keywords:
Social interaction
Gaze
Eye-tracking
Joint attention
Hyperscanning
Mentalizing
Autism

ABSTRACT

Tracking eye-movements provides easy access to cognitive processes involved in visual and sensorimotor processing. More recently, the underlying neural mechanisms have been examined by combining eye-tracking and functional neuroimaging methods. Apart from extracting visual information, gaze also serves important functions in social interactions. As a deictic cue, gaze can be used to direct the attention of another person to an object. Conversely, by following other persons' gaze we gain access to their attentional focus, which is essential for understanding their mental states. Social gaze has therefore been studied extensively to understand the social brain. In this endeavor, gaze has mostly been studied from an observational perspective using static displays of faces and eyes. However, there is growing consent that observational paradigms are insufficient for an understanding of the neural mechanisms of social gaze behavior, which typically involve active engagement in social interactions. Recent methodological advances have allowed increasing ecological validity by studying gaze in face-to-face encounters in real-time. Such improvements include interactions using virtual agents in gaze-contingent eye-tracking paradigms, live interactions via video feeds, and dual eye-tracking in two-person setups. These novel approaches can be used to analyze brain activity related to social gaze behavior. This review introduces these methodologies and discusses recent findings on the behavioral functions and neural mechanisms of gaze processing in social interaction.

Contents

* Corresponding author. Tel.: +49 221 478 87145.
E-mail address: ulrich.pfeiffer@uk-koeln.de (U.J. Pfeiffer).

0149-7634/$ – see front matter © 2013 Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.neubiorev.2013.07.017

1. Introduction

1.1. The special case of gaze in social cognition

Whenever we look at a face, the eyes are the primary and most consistent target of our visual attention from early infancy on (Haith et al., 1977; Walker-Smith et al., 1977). Despite the emergence of other means to navigate the social world (e.g. language), gaze remains a crucial cue system for our understanding of others throughout adulthood and serves a variety of social–cognitive functions beyond mere visual detection (e.g. Frischen et al., 2007). It has been related to the seeking of information, signaling interpersonal attitudes, regulating the synchronicity of speech during dialogue, and it plays a significant role in the regulation of interpersonal distance (Argyle et al., 1973; George and Conty, 2008). Furthermore, the eye region provides information related to a person's identity, emotional state, and focus of visual attention. The latter is a result of the unique morphology of the human eye (Kobayashi and Kohshima, 2001): non-human primates generally have darkened eyes which makes it difficult to distinguish the iris from the surrounding sclera. In contrast, the human eye is characterized by an exposed, depigmentated sclera surrounding the dark-colored iris. The development of these features facilitates the detection of the gaze direction of other individuals (Emery, 2000), which provides an important cue to the thoughts of others regarding entities in a shared environment and thereby to their mental states. Accordingly, social gaze has been termed a 'window into social cognition' (Shepherd, 2010). Hence, the behavioral functions and neural mechanisms of gaze behavior are of interest not only for neuroscience, but for a wide range of disciplines encompassing social psychology, linguistics, human–computer interaction, as well as developmental and evolutionary psychology.

1.2. Non-interactive methods to study social gaze

Until recently, gaze behavior in social contexts has been studied using comparably static methods. A large body of the literature has relied on gaze-cueing paradigms in which the influence of a static gaze cues on attentional processing is examined (e.g. Frischen et al., 2007; Langton et al., 2000). In these paradigms, an attentional cue towards a certain object or location is exerted by a picture of a real face (e.g. Hood et al., 1998; Mason et al., 2005), a virtual agent (e.g. Nuku and Bekkering, 2008; Pelphrey et al., 2003), or simply a symbolic drawing (e.g. Friesen and Kingstone, 1998). This approach has proven extremely helpful in unraveling the effects of social orientation on attentional processing. Another class of studies has used more dynamic stimulus materials including videos of real persons or virtual agents moving their eyes towards or away from a participant (e.g. Kuzmanovic et al., 2009; Pelphrey et al., 2004; Schilbach et al., 2006; Von dem Hagen et al., 2013). These experiments have often been complemented by concurrent recordings of participants' eye-movements using eye-tracking devices which can be applied in behavioral as well as functional imaging settings. While such 'diagnostic' eye-tracking (Duchowski, 2007) provides insights about a person's focus of visual attention, further important cues to cognitive and affective processes can be obtained by pupillometry (Granholm and Steinhauer, 2004; Laeng et al., 2012). For example, it has been shown that increases of pupil diameter correlates with switches of attention (e.g. Karatekin et al., 2004), increases in cognitive load and task difficulty (e.g. Kahneman and Beatty, 1966), motor preparation (e.g. Van der Molen et al., 1989), and emotional processing (e.g. Steinhauer et al., 1983). As all these processes play a role in social interactions, pupil diameter is an important source of information in studies of social cognition. However, all the methods mentioned above have in common that they do not capture the interactive nature of real-world social cognition (Schilbach et al., 2013). One major aim of this review is therefore to present novel methodological developments which allow studying gaze in truly interactive settings and to integrate the findings obtained with these methods with previous research.

1.3. Motivation of this review

In the past, social cognition has been studied from a detached, observational perspective in tasks involving inert social stimuli (*offline cognition*), which has led to a situation in which social cognition is studied without actual social interaction in what has been termed 'isolation paradigms' (Becchio et al., 2010). Recent claims emphasized that the active engagement with others in interaction (*online cognition*) plays a particular role in understanding other minds (Schilbach et al., 2013) and might underlie the development of our ability to think about others, rather than the other way round (Reddy and Morris, 2004). A growing number of researchers has therefore postulated the study of social interaction from an interactor's instead of an observer's point of view (e.g. Becchio et al., 2010; De Jaegher and Di Paolo, 2007; De Jaegher et al., 2010; Froese and Fuchs, 2012; Hobson, 1991; Konvalinka and Roepstorff, 2012; Marsh et al., 2009; Pfeiffer et al., 2013; Reddy and Morris, 2004; Riley et al., 2011; Schilbach et al., 2013). The importance of studying behavior and neural activity in truly interactive contexts is particularly important in studies of social gaze, because social gaze always involves two individuals who are engaged with one another face-to-face and in real-time. In the last years, the wealth of literature based on applying 'conventional' (i.e. non-interactive) methods to the study of social gaze has been complemented by exciting methodological developments which allow studying gaze in interaction These developments and related new insights into the neurobiology of social gaze will be the focus of this review.

The structure of this review is as follows. In Section 2, a brief overview is provided regarding the function and processing of gaze in social contexts. Results reviewed in this part have been obtained with conventional (i.e. non-interactive) methods. Emery (2000) has identified mutual gaze, gaze aversion, gaze-following, joint attention, and shared attention as the core processes constituting what will be termed *social gaze* throughout this article. This section does not represent a comprehensive review but rather provides an overview and update of key aspects of social gaze that have been discussed in more detail elsewhere (e.g. Carlin and Calder, 2013; Emery, 2000; George and Conty, 2008; Haxby et al., 2002; Itier and Batty, 2009; Langton et al., 2000; Nummenmaa and Calder, 2009; Shepherd, 2010). In Section 3, the major focus of this article will then be on novel research methods which can be used to disentangle the neural mechanism underlying gaze behavior in dynamic, real-time social interactions—an aspect that is greatly underrepresented in the current literature. In Section 4, novel findings obtained with interactive techniques are discussed and integrated with previous research to provide a detailed picture of the neural mechanisms supporting joint attention, which has been described as the most pivotal non-verbal skill enabling an understanding of other minds (e.g. Clark, 1996; Mundy and Newell, 2007; Tomasello et al., 2005). Section 5 discusses new insights into impairments of gaze-based social interactions in autism spectrum disorder (ASD). ASD is a developmental disorder which is characterized by deficits in communication and social interaction (Baron-Cohen and Belmonte, 2005). In particular, impairments in social gaze and the underlying neural mechanisms are characteristic for ASD (e.g. Dalton et al., 2005; Pelphrey et al., 2005; Von dem Hagen et al., 2013). The study of interactive gaze behavior in ASD might hence provide a key to understanding the core deficits of this disorder. Eventually, Section 6 discusses a putative neurofunctional model of gaze in interaction on the basis of the previous sections

Please cite this article in press as: Pfeiffer, U.J., et al., From gaze cueing to dual eye-tracking: Novel approaches to investigate the neural correlates of gaze in social interaction. Neurosci. Biobehav. Rev. (2013), http://dx.doi.org/10.1016/j.neubiorev.2013.07.017