Neuropsychologia 75 (2015) 330–340

Contents lists available at ScienceDirect

Neuropsychologia

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

EEG oscillations reflect the complexity of social interactions in a non-verbal social cognition task using animated triangles

Christine Blume [a,b], Julia Lechinger [a,b], Renata del Giudice [a,b], Malgorzata Wislowska [a], Dominik P.J. Heib [a,b], Manuel Schabus [a,b,*]

[a] University of Salzburg, Department of Psychology, Laboratory for Sleep, Cognition and Consciousness Research, Austria
[b] University of Salzburg, Centre for Cognitive Neuroscience Salzburg (CCNS), Austria

ARTICLE INFO

Article history:
Received 1 December 2014
Received in revised form
28 May 2015
Accepted 6 June 2015
Available online 22 June 2015

Keywords:
EEG
Theory of Mind
Social cognition
Oscillations
TRD/TRS

ABSTRACT

The ability to attribute independent mental states (e.g. opinions, perceptions, beliefs) to oneself and others is termed Theory of Mind (ToM). Previous studies investigating ToM usually employed verbal paradigms and functional neuroimaging methods. Here, we studied oscillatory responses in the electroencephalogram (EEG) in a non-verbal social cognition task.

The aim of this study was twofold: First, we wanted to investigate differences in oscillatory responses to animations differing with regard to the complexity of social "interactions". Secondly, we intended to evaluate the basic cognitive processes underlying social cognition. To this end, we analyzed theta, alpha, beta and gamma task-related de-/synchronization (TRD/TRS) during presentation of six non-verbal videos differing in the complexity of (social) "interactions" between two geometric shapes. Videos were adopted from Castelli et al. (2000)and belonged to three conditions: Videos designed to evoke attributions of mental states (ToM), interaction descriptions (goal-directed, GD) and videos in which the shapes moved randomly (R).

Analyses revealed that only theta activity consistently varied as a function of social "interaction" complexity. Results suggest that ToM/GD videos attract more attention and working-memory resources and may have activated related memory contents. Alpha and beta results were less consistent. While alpha effects suggest that observation of social "interactions" may benefit from inhibition of self-centered processing, oscillatory responses in the beta range could be related to action observation. In summary, the results provide insight into basic cognitive processes involved in social cognition and render the paradigm attractive for the investigation of social cognitive processes in non-verbal populations.

1. Introduction

The ability to attribute independent mental states such as opinions, perceptions, beliefs and attitudes to oneself and others forms the basis for the prediction and explanation of human behavior. It can thus be considered a key ability allowing humans to understand their social environment. These "mind-reading" capacities (Baron-Cohen, 1995) are often subsumed under the term "Theory of Mind" (ToM, Premack and Woodruff, 1978) and a distinct neuronal system has been suggested to underlie them (Baron-Cohen, 1994). During the last two decades, the question of whether and where one could localize the neuronal underpinnings of the ability to "read" other people's minds has stimulated considerable research activity. The majority of these studies has made use of functional imaging techniques providing converging evidence that the anterior paracingulate or medial prefrontal cortex (mPFC), the superior temporal sulci (STS) as well as the temporal poles (bilaterally) are regions involved in ToM-related processes (see e.g. Gallagher and Frith, 2003; see Schurz et al. (2014) for meta-analysis). In line with this, children with autism spectrum disorders (ASD) show abnormalities in the activity of the mPFC, the STS and the amygdaloid complex amongst other regions (see Siegal and Varley (2002) for review).

Research has made use of a variety of different paradigms to study ToM processes. Roughly, we can distinguish between two major categories, namely verbal and non-verbal tasks. Tasks

* Corresponding author at: University of Salzburg, Centre for Cognitive Neuroscience (CCNS), Laboratory for "Sleep, Cognition and Consciousness Research", Hellbrunner Str. 34, A-5020 Salzburg, Austria.

E-mail addresses: christine.blume@sbg.ac.at (C. Blume), julia.lechinger@sbg.ac.at (J. Lechinger), renata.delgiudice@sbg.ac.at (R. del Giudice), malgorzata.wislowska@sbg.ac.at (M. Wislowska), dominik.heib@sbg.ac.at (D.P.J. Heib), manuel.schabus@sbg.ac.at (M. Schabus).

http://dx.doi.org/10.1016/j.neuropsychologia.2015.06.009

employed in the former category usually require participants to e.g. read lists of words (Baron-Cohen et al., 1994) or read and understand stories (Fletcher et al., 1995; Gallagher et al., 2000; Happé et al., 1996). The latter category, in contrast, uses non-verbal stimulus material such as cartoons (Brunet et al., 2000; Gallagher et al., 2000; Pineda and Hecht, 2009). It has been demonstrated that irrespective of the modality of the stimulus material (i.e. verbal vs. non-verbal), the same brain regions are activated (Brunet et al., 2000; Gallagher et al., 2000; Kobayashi et al., 2007). However, despite many of these tasks not requiring verbal responses, they still need participants to understand and follow verbal instructions and to behaviorally indicate their choice.

In 2000, Castelli et al. introduced another paradigm, which could circumvent those limitations. Specifically, Castelli et al. (2000) studied brain activation in response to the presentation of short non-verbal videos (also known as Frith–Happé stimuli) designed to evoke attributions of goals and mental states by their kinetic properties alone. Heider and Simmel (1944) had already shown earlier that even contingent movements of simple geometric shapes could evoke mental state attributions, which were later found to be independent from the stimuli themselves (Berry et al., 1992; Berry and Springer, 1993). The videos employed by Castelli et al. (2000) comprised three different categories of animations: Theory of Mind (ToM), goal-directed (GD) and random (R). In the ToM condition, the behavior of two triangles was designed to evoke attributions of complex mental states (i.e. persuading, mocking, surprising) while in GD animations, triangles behaved in a simple, purposeful way, where one triangle's behavior determined the other's (i.e. dancing, chasing, following). In the R condition, triangles moved without any interaction or purpose (i.e. like billiards balls, drifting). Results from another study by Abell et al. (2000) supported the validity of this kind of animations. In their positron emission tomography (PET) study, Castelli et al. (2000) were able to show that regional cerebral blood flow (rCBF) was increased for ToM compared to R videos in four regions (temporoparietal junction, basal temporal region, extrastriate gyrus and mPFC) while the GD condition was characterized by intermediate rCBF (i.e. decreased rCBF compared to ToM videos and increased rCBF compared to R videos). Going beyond these findings, results from studies using similar stimuli suggest that the perception and understanding of social (ToM and GD) vs. non-purposeful mechanical (R) movements, in part, involves distinct neural networks (Blakemore et al., 2003; Martin and Weisberg, 2003).

We propose that the paradigm introduced by Castelli et al. (2000) is truly non-verbal in the sense that it does not even require participants to attend to task instructions, but merely to fixate and watch. In our opinion, this renders the paradigm highly attractive for research involving e.g. prelingual children as well as non-communicative clinical populations such as disorder of consciousness (DOC) patients, who often have impaired verbal and motor abilities.

Besides these aspects, we propose that investigating oscillatory changes in the EEG holds valuable advantages. First, there is a sound body of research supporting a functional interpretation of these changes linking oscillatory activity to basic cognitive processes (Başar et al., 2001a, 2001b; Fingelkurts and Fingelkurts, 2010; Klimesch, 1999b). Thus, this approach promises insight into differences in basic cognitive processes involved in the processing of videos varying with regard to the complexity of social interactions. Interestingly, just recently Schaafsma et al. (2015) argued for a reformulation of the ToM concept through a systematic deconstruction into basic component processes (e.g. perceptual discrimination and categorization of stimuli and executive processes). According to the authors, this deconstruction should then be followed by a hierarchical reconstruction and eventually result in a scientifically traceable concept. From this perspective, investigating oscillatory EEG activity with a well-established paradigm could provide insight into the basic cognitive processes involved in ToM and social cognition more generally. Besides these aspects, EEG measurements are often easier to perform than imaging studies, as for example measurements are not precluded by ferromagnetic material in the participant's body or other (medical) equipment. Moreover, the noisy and narrow scanner environment, which is potentially scaring, is circumvented.

To the best of our knowledge, there, however, is no study investigating oscillatory changes induced by the Frith–Happé stimuli. The present study, therefore, investigates EEG effects of social cognition processes adopting six of the videos: two Theory of Mind (ToM), two goal-directed (GD) and two random (R) videos. These stimuli are thought to differ with regard to the complexity of the social cognitive processes they evoke. Complexity here denotes the amount of information that needs to be integrated in order to understand the videos' content. Specifically, R videos only require participants to observe movements (i.e. physical knowledge) while GD videos additionally require the integration of their interpretation (i.e. goal knowledge). ToM videos as the most complex video category, additionally, require the integration of mental state knowledge.

“Social cognition” is an umbrella term for cognitive processes underlying interactions among conspecifics (i.e. other members of the same species). Specifically, it describes those processes that subserve the highly complex, variable and flexible social behaviors seen in humans (e.g. Adolphs, 1999). Despite the complexity of these behaviors, they can be broken down into basic cognitive processes such as attention and memory-related processes. Recently, a series of three publications investigated the relationship between basic cognitive processes and the observation of the Frith–Happé stimuli by means of eye-tracking measures (Klein et al., 2009; Roux et al., 2012; Zwickel et al., 2011). Specifically, Klein et al. (2009) found that greater complexity of the social interactions was correlated with longer fixation duration, which indicates deeper and more extensive processing. At the same time, greater processing depth has been shown to involve more processing resources, i.e. attention and working memory resources (Eysenck and Eysenck, 1979; Griffith, 1976; Johnston and Heinz, 1978). Zwickel et al. (2011) replicated Klein et al.'s findings and, moreover, showed that the time the participants' eye gaze fell within the triangles was longer for ToM than for R videos with GD videos being linked to intermediate durations. This was interpreted as an indicator of how much importance participants attributed to the triangles' behavior and suggests that more attention was allocated to more complex triangle interactions. However, measures of fixation duration may be confounded by kinematic properties of the videos, wherefore Roux et al. (2012) used another eye-tracking measure. From their results, they concluded that animate motion in GD and ToM videos captures more attention than the triangles' behavior in the R videos irrespective of kinematic confounds.

On the other hand, links between oscillatory changes in the lower frequency range (frontal theta ERS and parietal alpha ERD) and cognitive processes related to memory and especially attention are well-established (Başar et al., 2000; Deiber et al., 2009; Klimesch, 1997, 1999a; Missonnier et al., 2006a; Ray and Cole, 1985; Sauseng et al., 2007; Weiss et al., 2000). Moreover, theta oscillations seem to be related to excitatory processes whereas alpha has repeatedly been linked to inhibitory processes (Jensen and Mazaheri, 2010; Klimesch, 1999a; Klimesch et al., 2007, 2004; Mazaheri et al., 2009). We reason that more complex stimuli require more complex integration processes, which also affects basic cognitive processes. These processes are, in turn, mirrored by oscillatory changes in different frequency bands (Fingelkurts and