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Research report

Cortical oscillatory dynamics in a social interaction model

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HIGHLIGHTS

- ▶ Social choices were partly reactive and partly proactive.
- ▶ Approach choices were associated with higher induced responses.
- ▶ These effects were more salient in subjects predisposed to approach behaviors.

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ABSTRACT

In this study we sought to investigate cortical oscillatory dynamics accompanying three major kinds of social behavior: aggressive, friendly, and avoidant. Behavioral and EEG data were collected in 48 participants during a computer game modeling social interactions with virtual 'persons'. 3D source reconstruction and independent component analysis were applied to EEG data. Results showed that social behavior was partly reactive and partly proactive with subject's personality playing an important role in shaping this behavior. Most salient differences were found between avoidance and approach behaviors, whereas the two kinds of approach behavior (i.e., aggression and friendship) did not differ from each other. Comparative to avoidance, approach behaviors were associated with higher induced responses in most frequency bands which were mostly observed in cortical areas overlapping with the default mode network. The difference between approach- and avoidance-related oscillatory dynamics was more salient in subjects predisposed to approach behaviors (i.e., in aggressive or sociable subjects) and was less pronounced in subjects predisposed to avoidance behavior (i.e., in high trait anxiety scorers). There was a trend to higher low frequency phase-locking in motor area in approach than in avoid condition. Results are discussed in light of the concept linking induced responses with top-down and evoked responses with bottom-up processes.

1. Introduction

For humans as social beings interactions with other people constitute the most important part of their lives. Outcomes of these interactions may vary from extreme violence including murder to acts of charity. Why a particular individual in a particular situation chooses one or another way of interaction with a particular person? This is perhaps the most important question psychology tries to elucidate. Eysenck and Wilson [1] once noted that there are only three major ways of dealing with the challenge presented by other people. The first choice is aggression and hostility, the second is fear and flight, and the third is social interaction. They suggested that these three kinds of interpersonal relations are reflected in personality dimensions of Psychoticism, Neuroticism, and Extraversion, respectively. Somewhat transformed, these ideas have found their implementation in personality dimensions of Agreeableness, Neuroticism, and Extraversion of the most currently popular model of personality – the so-called Big Five [2].

Understanding brain functioning associated with social behavior is utterly important both for theoretical and practical reasons. Firstly, human brain largely evolved in the process of complex social interactions [3]. Studies of natural, everyday social cognition show that diverse cognitive processes are focused on people's relationships with their acquaintances and associates [4]. Furthermore, virtually all human activity is shaped by social context or has social implications, resulting in a continuous need to monitor social contexts and meanings [5]. Secondly, understanding the brain activity which is associated with social cognition may help to

Abbreviations: DMN, default mode network; EEG, electroencephalography; FDR, false discovery rate; fMRI, functional magnetic resonance imaging; GLM, general linear model; ICA, independent component analysis; OFC, orbitofrontal cortex; ToM, theory of mind.

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elucidate causes underlying some disturbances in social behavior [5]. In humans, investigation of brain activity during natural social interactions is extremely difficult. Therefore most relevant studies investigate brain activity via some kind of neuroimaging technique, such as fMRI during watching of social interactions [6], or during virtual interactions in some kind of a computer game, such as the Prisoner's Dilemma game [7], the game of Chicken [8,9], an economic trust game [10], the Ultimatum Game [7] and so on. These studies have revealed a network of brain areas whose activity correlates with social behavior. Not surprisingly many of these areas, such as the amygdale, the cingulate gyrus, the parahippocampal gyrus, the fusiform gyrus, the insula, the orbitofrontal cortex (OFC) are associated with motivational and emotional circuits [11–14]. Besides, there is ample evidence that the so-called mirror neuron system (cortical brain cells in the premotor cortex that fire during both the action and observation of motoric behavior) [15,16] is involved in the development of social cognitive processes that allow effective social interactions [17–21]. Furthermore, theory of mind (ToM) is the ability to cognitively represent a person's mental states, such as their intentions, beliefs, and desires, and thereby to understand and predict their behavior [22]. Many neuroimaging studies that used various kinds of paradigms and test materials to explore the neural substrate of ToM show activation of discrete parts of the brain, including the medial prefrontal cortex, temporal pole, inferior frontal cortex, etc. [23–25]. Finally, the most intriguing findings and ideas are associated with the so-called default mode network (DMN). The DMN is a constellation of brain areas including the medial prefrontal cortex, the temporo-parietal junction, and the precuneus, which decrease their activity during a wide number of different goal-oriented tasks as compared to passive 'rest' tasks [26]. Intriguingly, several DMN regions are also related to social cognition [27,28]. Mitchell [28] suggested that social cognition is one of the functions of the DMN. In line with this hypothesis recent studies have revealed DMN abnormalities in autistic patients [29,30] and in patients with social phobia [31]. Cortical oscillatory dynamics that are associated with these processes are less studied [32–35].

In this study, we aimed to investigate behavioral choices and oscillatory dynamics that accompany these choices in a specially designed computer game of social interactions with virtual persons. Participants were presented with pictures of emotional (angry, neutral, and happy) facial expressions and were asked to make a choice out of three variants of social behavior: 'attack', 'avoid' or 'make friends'. We expected that participants' behavior would be partly reactive and partly proactive. The reactive part implies that they would more frequently attack angry faces and would more frequently offer friendship to happy faces. The proactive behavior would partly depend on preceding experience in this game and partly on participants' predisposition, for example, his or her personality. We expected that aggressive individuals would choose attack more frequently, anxious individuals would choose avoidance more frequently, and sociable individuals would choose friendship more frequently. Post-stimulus oscillatory dynamics would also be associated with the choice to come and the subject's personality. With this regard, both evoked and induced responses were analyzed using wavelet transform, independent component analysis (ICA), and source localization techniques. Evoked and induced oscillations differ in their phase-relationships to the stimulus. Evoked oscillations are phase-locked to the stimulus, whereas induced oscillations are not. Although functional correlates of evoked and induced oscillations are not fully understood, it is generally assumed that they represent different aspects of stimuli processing [36]. We expected that major effects would be found in cortical regions associated with the well known 'social' cortical networks, such as the DMN.

2. Method

2.1. Subjects

The social game data were collected in a sample of 48 subjects (26 men; age range 18–30 years). The sample consisted of healthy, right-handed volunteers with normal or corrected to normal vision who received a sum equivalent to about 5% of the monthly living wage for participation. All applicable subject protection guidelines and regulations were followed in the conduct of the research in accordance with the Declaration of Helsinki. All participants gave informed consent to the study. The study has been approved by the Institute of Physiology ethical committee.

2.2. Instruments and procedures

Subjects sat in a soundproof and dimly illuminated room. First, the spontaneous EEG was registered during about 6 min including alternating 2 min intervals with eyes open and eyes closed. As stimulation we used an ensemble of the photographs presented by Ekman and Friesen [37]. We selected 30 photographs, specifically, 5 different females and 5 different males with 3 different facial expressions (angry, happy, and neutral). The pictures were presented black and white (17 cm $\times$ 17 cm) and displayed on a screen at a distance of 120 cm from the subject. To familiarize the subjects with the stimuli and to reduce the effect of novelty participants were first presented with a simple discrimination task. In this task, they were instructed to press '1' or '2' upon presentation of, respectively, male, or female face. After a short break the participants were presented with the instruction for the social interaction task. They were asked to imagine that faces, which they see at the screen, are living persons whom they have to interact with. They had to choose one out of three options: 'attack', 'avoid', or 'make friends' (pressing '1', '2', or '3' button, respectively). Vis-à-vis' 'reaction' might be different, depending on his\her 'character'. As a result, the participant gained or lost points which afterwards were added or, respectively, subtracted from his\her fee. This latter condition was not necessary for the aim of the study and was introduced solely for the purpose of maintaining the subject's interest and attention during the game. In reality, all three choices on average received equal zero reinforcement.

First, a fixation cross appeared at the center of the screen for 1 s. Then a face picture was presented. Angry, happy, and neutral faces were delivered randomly, and inter-stimulus-interval randomly varied between 4 and 7 s. After the button press, a feedback announcement appeared at the screen for 1 sec, such as: '0 points', '+20 points', or '−20 points'. The number of face stimulations was 150 for each subject, including 50 faces of each category. After the experiment, the subjects filled out a set of psychometric questionnaires and were debriefed.

Personality was assessed using three scales, which were selected to measure aggressive, avoidant, and sociable tendencies. Aggressiveness was measured by the Hostility scale from the Buss–Perry aggression scales [38]. Trait Anxiety was measured by the Spielberger State Trait Anxiety Inventory [39]. Sociability was measured by the respective scale from a short form of the Eysenck Personality Profiler [40,41].

2.3. EEG data acquisition

32 EEG electrodes were placed on the subject's scalp. The electrodes were mounted in an elastic cap on the positions of the international 10–20 system which ensured homogenous scalp coverage. A mid-forehead electrode was the ground. The electrode resistance was maintained below 5 kΩ. The signals were amplified with a multichannel biosignal amplifier with bandpass 0.05–70 Hz,