Biological Psychology 124 (2017) 57–64

Contents lists available at ScienceDirect

Biological Psychology

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

Sensitivity of the human mirror neuron system for abstract traces of actions: An EEG-study☆

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ARTICLE INFO

Article history:
Received 17 August 2016
Received in revised form 19 January 2017
Accepted 22 January 2017
Available online 23 January 2017

Keywords:
Mu-activity
Mirror neuron system
Action perception
Neuroaesthetics
Electroencephalography

ABSTRACT

Theories of neuroaesthetics assume, that looking at traces of actions used in creating artwork (e.g. brush marks) is associated with a simulation of these actions in the observer's sensorimotor-cortex. The aim of the current study is to dissociate the activation of the sensorimotor-cortex by the observation of action traces from associated visual processes.

Twenty-eight participants observed handmade graphics (acrylic paint on paper) of different complexity (line, triangle, shape of a house) and computer-generated counterparts. Central mu-activity, as an index of sensorimotor-cortex activity, and occipital alpha-activity, as an index of visual cortex activity were recorded in the 8–13 Hz EEG-band.

In line with the hypothesis, mu-activity at electrode C4 is sensitive for the complexity of handmade ($p = 0.001$), but not computer-generated graphics ($p > 0.500$). In contrast, occipital alpha-activity is sensitive for the complexity of both handmade and computer-generated graphics ($p < 0.001$). Furthermore, the more empathic the participants rated themselves, the stronger mu-suppression was induced by handmade graphics compared to computer-generated graphics (electrode C4; $r = -0.612$, $p = 0.001$). These results support the involvement of the sensorimotor-cortex in the recognition of action traces and strengthen evidence that individuals scoring high in emotional empathy feature a particularly responsive mirror neuron system.

1. Introduction

Theories of embodied simulation in social perception assume that humans gain knowledge about the actions, intentions, sensations, and emotions of others through automatic simulation processes within their brains (for reviews see Gallese, 2007; Gallese, Keysers, & Rizzolatti, 2004). Involved in these simulation processes is the mirror neuron system, which is activated when actions and motions are self-performed or observed.

The sensorimotor embodiment of observed actions within the mirror neuron system (either depicted in paintings or performed by actors) might form the basis of the spectator's empathic and aesthetic response towards the artwork (Ticini, Urgesi, & Calvo-Merino, 2015). For instance, cortico-spinal excitability was increased in observers of Michelangelo's *Expulsion from Paradise* painting (depicting hand extension movement), but not when comparable photographs of natural hands had to be observed (Battaglia, Lisanby, & Freedberg, 2011). On a neuronal level, the observation of embedded motions in paintings reduces activity of inhibitory connections between the dorsal premotor cortex and the primary motor cortex (Concerto et al., 2016).

However, the mirror neuron system might not only be sensitive to observed actions, but also to the product of those actions, like sounds of actions (Gazzola, Aziz-Zadeh, & Keysers, 2006), speech (D'Ausilio et al., 2009), handwriting and scribble (Heimann, Umiltà, & Gallese, 2013). In their *embodied simulation account of aesthetics* Freedberg and Gallese (2007) proposed that the mirror neuron system might also simulate the movements used to create artwork, and that this motor simulation might be part of the aesthetic experience. For instance pointillist-style paintings are perceived as more aesthetically pleasing, when the paintings were primed with actions compatible to the artists painting style, compared to incompatible movements (Ticini, Rachman, Pelletier, & Dubal, 2014). Two neurophysiological studies tested whether the mirror neuron system is involved in the perception of abstract action traces in artwork, utilizing mu-activity as an index of mirror neuron activity (Umiltà, Berchio, Sestito, Freedberg, & Gallese, 2012)

☆ Parts of this research were presented at the 40th Annual Meeting of the German Society for Psychophysiology and Its Application in Lübeck, Germany, 2014.

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http://dx.doi.org/10.1016/j.biopsycho.2017.01.010
0301-0511/

and event related potentials (Sbriscia-Fioretti et al., 2013). Results of both studies indicate that mirror neuron system might respond more strongly to handmade original abstract art as compared to computer-generated counterparts. However, the handmade and computer-generated graphics differed not only with respect to their origin, but also with respect to the level of detail and complexity (e.g. smoothness of the contour or three-dimensional information like shadows). Therefore, the results of these studies might be confounded with effects of visual complexity. Even more, alpha-activity, which is affected by the complexity of visual stimuli (Gale, Christie, & Penfold, 1971) and which is measured in the same frequency band as mu-activity (Pineda, 2005), might overshadow mu-activity, leading to confounded results.

The aim of this study is to dissociate motor-simulation from visual processes. As in previous studies (Sbriscia-Fioretti et al., 2013; Umiltà et al., 2012), handmade and computer-generated graphics are used. Both types of graphic were altered in their complexity. Central mu-activity, as an index of activity of the mirror neuron system (Arnstein, Cui, Keysers, Maurits, & Gazzola, 2011; Pineda, 2005), and alpha-activity as an index of visual processes were recorded (Gale et al., 1971). If central mu-suppression is associated with the perception of action traces, it should be modulated by the complexity of handmade but not by the complexity of computer-generated graphics. In contrast, alpha-activity should be modulated by the visual complexity regardless of the graphics' origin. Several studies indicate that the mirror neuron system is involved in empathic processes (for an overview see Iacoboni, 2009). Specifically, mu activity within the EEG seems to be affected through empathic processes (e.g. Hoenen, Schain, & Pause, 2013). Therefore, it was further tested whether self-reported empathic abilities positively covary with the sensitivity of the mirror neuron system for traces of actions.

2. Method

2.1. Participants

A total of 33 right-handed (assessed using Annett, 1967) volunteers participated in the study. All participants reported to be healthy, and free of neurological or psychiatric conditions. Visual acuity was assessed using Landolt rings (EN ISO 8596), and was always better than 90% normal vision (size of the smallest distinguishable detail at 0.75 m distance is smaller than 0.24 mm). Five participants were excluded due to technical problems ($n = 3$; construction noise; sweaty head resulting in excessive noise in EEG-data), outliers in the attention task ($n = 1$; see section 2.3) and strong motor activity while EEG was recorded ($n = 1$). The final sample consisted of 19 females and 9 males ($N = 28$) with a mean age of 25 years ($SD = 6$; range: 18–41). Participants had no special expertise in drawing pictures by hand or using a computer (drawing by hand: $M = 33$, $SD = 30$; using computers: $M = 17$, $SD = 24$; rated on computer-based visual analog scales: length 18.5 cm; 0 = *never*, 100 = *very frequently*).

Participants gave written informed consent and were compensated with course credit or €10. The study was approved by the ethics committee of the Faculty of Mathematics and Natural Sciences of the Heinrich-Heine-University Düsseldorf.

2.2. Material

A set of 144 digital color pictures was used, showing handmade or computer-generated graphics (see Fig. 1). All pictures were shown in a resolution of 600 × 800 pixels and a color depth of 24 bit. The digitized handmade graphics were painted using a flat brush and acrylic paint on white paper. The computer-generated graphics were obtained by applying a digital texture-filter (*crystallize*: size 4; Corel Photopaint X4, Corel Corp.) on the handmade graphics, removing the brush-marks, while keeping a complex texture and the same shape as the handmade graphics. Complexity of graphics was operationalized by the number of straight strokes necessary to draw the graphic. For the low complexity condition a straight line (1 stroke), for medium complexity an acute triangle (3 strokes), and for high complexity the shape of a house (8 strokes) were used. In order to obtain more stimuli, each graphic was painted in four different colors (red, blue, green and violet) and shown in three different rotations (0°, 120°, and 240°). To keep participants attentive during EEG-recording, they were asked to count the number of control stimuli. Control stimuli were obtained by applying a digital texture-filter (*canvas*; Corel Photopaint X4, Corel Corp.) on the handmade and computer-generated graphics (see Fig. 1).

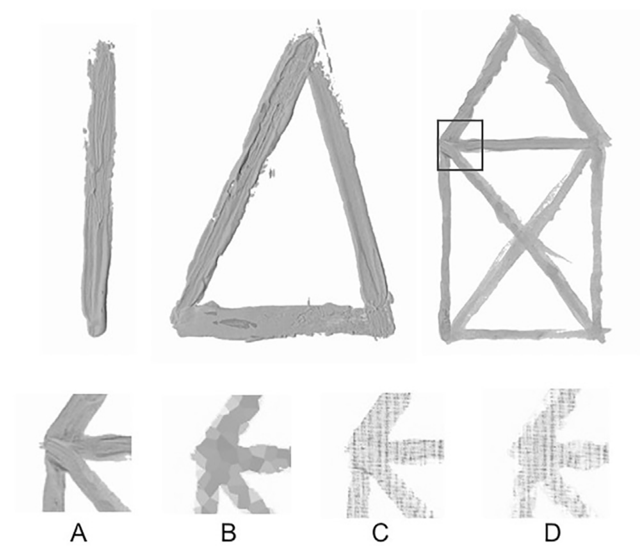

Fig. 1. Stimuli used in the study. The upper part depicts the handmade graphics in different complexities (from left to right: low complexity, medium complexity, high complexity, control stimuli). The rectangle indicates the area depicted in the lower part. The lower part depicts the different textures of the stimuli (magnified detail of the high complexity stimuli; A: handmade, B: computer-generated, C: handmade/control, D: computer-generated/control).

Pictures were shown (Presentation 16, Neurobehavioral Systems Inc., CA) on a TFT monitor (resolution: 1280 × 1024 pixel; model: Terra LCD 4319; Wortmann AG, Germany) at a distance of 75 cm to the participant's eyes, covering a visual angel of 8.4° vertical and 1.0° (line) and 6.1° (triangle and house) horizontal.

Additionally, participants completed the *Saarbrueck Personality Questionnaire on Empathy* (SPQ; Paulus, 2009), a German adaptation of the Interpersonal Reactivity Index (IRI; Davis, 1980). The SPQ is used to assess self-reported empathic abilities on four dimensions: fantasy (tendency to transpose oneself imaginatively in the feelings of fictions characters), perspective taking (tendency to adopt the psychological view of others), empathic concern (sympathy and concern for unfortunate others) and personal distress (feeling of unease in tense interpersonal settings; Davis, 1980). Each scale consists of four items ranging from 1 (low empathy) to 5 (high empathy). The SPQ has an internal consistency of chronbach's $\alpha > 0.70$ on each dimension (Paulus, 2012), similar to the internal consistency of the IRI (Davis, 1980).

2.3. Procedure

One trial consisted of a baseline (white screen; random duration: 2.25–2.75 s), and a stimulus (handmade graphic, computer-generated graphic or control stimulus; random dura-