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CEREBELLAR ACTIVITY AND CONNECTIVITY DURING THE EXPERIENCE OF DISGUST AND HAPPINESS

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Abstract—Previous research indicates that distinct subregions of the cerebellum are involved in the processing of different primary emotions. How this is achieved in terms of connectional specificity with other brain areas still needs to be elucidated. We employed functional magnetic resonance imaging in order to investigate cerebellar activation and connectivity relevant for the processing of two basic emotions. Thirty-four healthy women were presented with pictures that specifically elicited happiness and disgust with the instruction to rate the intensity of the experienced feelings. The contrasting of both affective conditions showed that disgust evoked activation of the vermis and the cerebellar hemispheres, whereas happiness-associated activation was restricted to the posterior cerebellum. Both emotions provoked increased connectivity of the cerebellum with limbic regions. The observed extended connectivity patterns can explain why cerebellar lesions are able to produce pronounced changes of affective experience in the afflicted patients.

Key words: cerebellar connectivity, psychophysiological interactions, happiness, disgust.

INTRODUCTION

Basic emotions provoke activation in specific cortical and subcortical regions. For example, functional magnetic resonance imaging (fMRI) investigations have shown consistently that the exposure to visual disgust elicitors leads to increased activation of the insula, the amygdala, the lateral orbitofrontal cortex (OFC), and the extrastriate cortex (e.g. Schienle et al., 2002a; Tettamanti et al., 2012). These regions are involved in interoceptive processes, selective attention and negative valence assignment. The experience of another basic emotion, happiness, involves the brain reward system, including basal ganglia regions (e.g. caudate nucleus) and the medial prefrontal cortex (e.g., Schienle et al., 2009; Tettamanti et al., 2012). Also, the amygdala and visual cortex regions have been repeatedly identified to be relevant for happiness processing, indicating that there are common brain areas that are crucial for all basic emotions.

Recently, another brain structure, the cerebellum, has received increased recognition that it significantly contributes to affective processing besides its role in motor and cognitive functions (Schmahmann and Caplan, 2006). Two lines of evidence support this notion. First, patients suffering from cerebellar lesions not only experience impairments in executive, visuo-spatial, and verbal abilities, but also show altered affective responses. This symptom cluster has been labeled cerebellar cognitive affective syndrome (CCAS; Schmahmann and Sherman, 1998). Especially when lesions encompass the vermis, dysregulation of affect can occur in different forms, such as blunting of affect, emotional lability, or impulsive affect (e.g., Schmahmann and Sherman, 1998; Turner et al., 2007; Paradiso et al., 2011).

Second, neuroimaging investigations have presented evidence that the cerebellum is involved in affective processing. In healthy individuals, visually elicited negative and positive affect has been consistently associated with cerebellar activation (e.g., Lane et al., 1997; Paradiso et al., 1997, 2003; Reiman et al., 1997; Bermpohl et al., 2006; Moulton et al., 2011).

Turner et al. (2007) conducted an fMRI study with individuals who had experienced cerebellar strokes. They demonstrated that the patients had a normal experience of unpleasant emotions, but this response was accompanied by reduced amygdala recruitment and increased engagement of prefrontal and insular regions relative to healthy controls. Moreover, the ability to experience pleasant feelings was reduced in the clinical group. These findings imply that the connectivity of the cerebellum with other nodes of the brain's affective network might be a crucial mechanism for the regulation of emotions.

The role of the cerebellum in distinct emotions has hardly been investigated so far. An exception is a recent fMRI experiment by Baumann and Mattingley (2012) who studied healthy volunteers, who categorized images that elicited happiness, anger, disgust, fear and sadness. All five emotions evoked localized cerebellar activation with relative specificity. As a shortcoming of this investigation it has to be noted that the authors did not analyze connectivity patterns, which would allow deeper insights into how the cerebellum shows emotion-

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Abbreviations: fMRI, functional magnetic resonance imaging; FWE, family-wise error; MNI, Montreal Neurological Institute; OFC, orbitofrontal cortex; PPI, psychophysiological interaction; ROI, region of interest.

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specific interactions with other brain regions. This was accomplished in an experiment by Tettamanti et al. (2012) who exposed their subjects to film clips for the elicitation of four basic emotions (fear, disgust sadness, happiness). The conducted effective connectivity analysis (dynamic causal modeling) indicated that the amygdala was involved in distinct functional integration effects with cortical networks processing sensorimotor, somatosensory, and cognitive aspects of the studied basic emotions. Unfortunately the cerebellum had not been integrated into the model.

Therefore, in the present study, we employed functional MRI in order to investigate cerebellar activation and connectivity patterns relevant for the processing of two basic emotions. The female participants were presented with pictures that are able to specifically elicit disgust and happiness with the instruction to rate the intensity of the experienced feelings. We hypothesized that affect elicitation would increase cerebellar activation as well as coactivation with limbic regions such as the insula and the amygdala. The sample had been restricted to women as they report greater disgust proneness than men (Schienle et al., 2002b) and show greater activation of prefrontal cognitive control areas during disgust elicitation (Caseras et al., 2007).

EXPERIMENTAL PROCEDURE

Sample

Thirty-four healthy women (mean age = 23 years; SD = 3.4; 80% University students) gave their informed consent for this study, which had been approved by the ethics committee of the University of Giessen. All participants had been screened to rule out psychiatric and neurologic disorders as well as serious medical illness. None of the participants was taking psychiatric medications at the time of testing.

Pictures and task

During the fMRI recording, the participants viewed pictures representing the affective categories DISGUST (e.g., worms, vomit, excrements), HAPPINESS (e.g., celebrations, appetizing food), and NEUTRAL (e.g., geometric Figures). Each picture category consisted of 15 pictures, which had been taken from two sets of pictures that are able to induce the two basic emotions with sufficient specificity (Schienle et al., 2002a, 2009). The scenes were shown for 4 s each in an event-related design. The presentation was pseudo-randomized with the restriction that two pictures of the same category were not allowed to follow each other. In addition, a null condition was introduced, where a fixation cross was shown for an interval ranging between 3.5 and 6 s. The design was repeated once. The women had been instructed to passively view the scenes.

Subsequent to the fMRI experiment, the subjects rated each stimulus on two 9-point Likert scales for experienced emotion intensity (for disgust and happiness; 1 = no feeling, 9 = very intense feeling).

MRI data acquisition and analysis

Brain images were acquired using a 1.5-Tesla whole-body tomograph (Magnetom Symphony, Siemens, Erlangen, Germany) with a standard head coil. For the functional imaging, 380 volumes were registered using a $T2^*$-weighted gradient echoplanar imaging sequence (EPI) with 30 slices covering the whole brain (slice thickness 4 mm; 1-mm gap, interleaved, repetition time = 3000 ms; echo time = 50 ms, flip angle = 90°, field of view = 192 mm × 192 mm; matrix size = 64 × 64). The orientation of the axial slices was parallel to the anterior/posterior commissure line. The first six volumes of the time series were discarded to account for saturation effects. Preprocessing (SPM8; Wellcome Trust Centre for Neuroimaging, University College London, United Kingdom) included slice-time correction, realignment, normalization to the Montreal Neurological Institute (MNI) brain coordinates and smoothing (isotropic three-dimensional Gaussian filter, full width at half maximum = 8 mm, high-pass filter = 128 s). The three experimental conditions HAPPINESS, DISGUST and NEUTRAL were modeled by a hemodynamic response function in the GLM. The six movement parameters of the rigid body transformation applied by the realignment procedure were introduced as covariates in the first-level general linear model. We computed different contrasts (DISGUST > NEUTRAL, HAPPINESS > NEUTRAL, DISGUST < > HAPPINESS) for each subject (first level) and then conducted second-level analyses. We studied within-group effects via one-sample *t*-tests for voxel intensities (*p*-threshold < .001; uncorrected). We report results with family-wise error (FWE) corrected *p*-values for exploratory whole brain analyses as well as for region of interest (ROI) analyses. The ROIs were derived from prior fMRI investigations of our group (Schienle et al., 2002a, 2009) on happiness and disgust processing (insula, amygdala, OFC, dorsolateral prefrontal cortex, ventrolateral prefrontal cortex, inferior parietal cortex, putamen, pallidum). Further the right and left cerebellar hemisphere and the vermis were considered ROIs. All ROIs were taken from the automatic anatomical labeling atlas (Tzourio-Mazoyer et al., 2002).

In addition, we performed correlation analyses (simple regression) in order to relate ROI activation with the affective ratings of the participants.

Psychophysiological interaction (PPI) analysis

To investigate emotion-specific effective connectivity (functional coupling) between ROIs, we conducted PPI analyses (Friston et al., 1997) for each subject. PPIs assess the extent to which an experimental factor modulates the connectivity of one brain region with others, in terms of condition-specific covariation in residuals. Given a specific seed region (e.g. the vermis), PPI identifies voxels which covary differentially with the seed region as a function of an experimental factor. For each participant, a PPI analysis was performed by setting up a design matrix containing three columns of