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Note

Neural correlates of mirth and laughter: A direct electrical cortical stimulation study

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ABSTRACT

Laughter consists of both motor and emotional aspects. The emotional component, known as mirth, is usually associated with the motor component, namely, bilateral facial movements. Previous electrical cortical stimulation (ES) studies revealed that mirth was associated with the basal temporal cortex, inferior frontal cortex, and medial frontal cortex. Functional neuroimaging implicated a role for the left inferior frontal and bilateral temporal cortices in humor processing. However, the neural origins and pathways linking mirth with facial movements are still unclear. We hereby report two cases with temporal lobe epilepsy undergoing subdural electrode implantation in whom ES of the left basal temporal cortex elicited both mirth and laughter-related facial muscle movements. In one case with normal hippocampus, high-frequency ES consistently caused contralateral facial movement, followed by bilateral facial movements with mirth. In contrast, in another case with hippocampal sclerosis (HS), ES elicited only mirth at low intensity and short duration, and eventually laughter at higher intensity and longer duration. In both cases, the basal temporal language area (BTLA) was located within or adjacent to the cortex where ES produced mirth. In conclusion, the present direct ES study demonstrated that 1) mirth had a close relationship with language function, 2) intact mesial temporal structures were actively engaged in the beginning of facial movements associated with mirth, and 3) these emotion-related facial movements had contralateral dominance.

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Abbreviations: ES, electrical cortical stimulation; fMRI, functional magnetic resonance imaging; HS, hippocampal sclerosis; MEP, motor evoked potential; EMG, electromyogram; SMA, supplementary motor area; BTLA, basal temporal language area.

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1. Introduction

Laughter, an essential part of daily life, consists of motor and emotional components, the latter of which is known as mirth (Arroyo et al., 1993). Indeed, appreciating or enjoying humor is associated with a feeling of mirth. Lesion studies have shown that humor consists of both cognitive and affective processing (Gardner, Ling, Flamm, & Silverman, 1975). Goel and Dolan (2001), in their pioneer functional magnetic resonance imaging (fMRI) study, showed that cognitive processing with semantic components was associated with the left hemisphere (left inferior frontal gyrus and posterior inferior temporal gyrus), while cognitive processing with semantic components involved the bilateral temporal cortices (bilateral posterior middle temporal gyrus and left posterior inferior temporal gyrus), and that affective processing was associated with reward processing system (medial ventral prefrontal cortex) (Goel & Dolan, 2001). This notion was confirmed by several lines of evidence using fMRI in healthy subjects (Amir, Biederman, Wang, & Xu, 2013; Mobbs, Greicius, Abdel-Azim, Menon, & Reiss, 2003; Moran, Wig, Adams, Janata, & Kelley, 2004; Watson, Matthews, & Allman, 2007). However, despite centuries of inquiry, the neural origins and pathways linking bilateral facial movements with mirth are still unclear.

Unilateral lower facial motor weakness (contralesional "mimetic palsy" or emotional facial paresis), which manifests during spontaneous smiling and weeping but not at all during voluntary muscle contraction, has been reported in patients with lesions involving mesial temporal structures (amygdala and hippocampus) (Hopf, Muller-Forell, & Hopf, 1992). This suggests that impairment of contralateral functional connections originating in mesial temporal structures leads to asymmetric emotional facial movements.

We report two patients with temporal lobe epilepsy who underwent subdural electrode implantation, and in whom electrical cortical stimulation (ES) of the cortices of the left basal temporal lobe elicited mirth, followed by laughter. By analyzing the features common to the two cases, we postulated that mesial temporal structures directly bridged mirth and laughter.

2. Materials and methods

2.1. Subjects

We enrolled 13 consecutive patients with medically intractable left temporal lobe epilepsy who underwent chronic subdural electrode implantation over the basal part of the temporal lobe for presurgical evaluation between March 2000 and December 2013. All the patients showed language dominance in the left hemisphere as assessed by the Wada test (Takayama et al., 2004), with the exception of one who demonstrated bilateral language representation. We systematically performed high-frequency ES at the basal part of the temporal lobe in order to map the basal temporal language area (BTLA), as this area is actively engaged in semantic language processing and preservation of the BTLA and its white matter connection previously led to preservation or improvement of verbal memory (Mikuni et al., 2006; Shimotake et al., 2014; Usui et al., 2003). In two of the 13 patients, mirth was elicited by high-frequency ES. Both patients had language dominance in the left hemisphere. Postoperative histology showed an intact hippocampus in one patient (Patient 1) and hippocampal sclerosis (HS) in the other (Patient 2). Neither laughter nor mirth occurred during the patients' habitual seizures, and Patient 2 showed mimetic facial palsy on the right side only when smiling and not at all during voluntary upward curving of the lips. The case of Patient 2 was reported preliminarily as a letter (Satow et al., 2003). The demographic details of Patients 1 and 2 are shown in the Supplementary Material.

2.2. High-frequency ES

High-frequency ES (50 Hz, square-wave pulse of alternating polarity with a pulse width of .3 msec, 1–5 sec, 1–15 mA) was applied to the basal temporal cortices through a pair of implanted electrodes to define the functional areas, especially those related to language function (Matsumoto et al., 2011). The amplitude of the electric current was increased gradually until positive motor symptoms (e.g., contraction of arms or facial muscles) or subjective perception of epileptic aura or somatosensory, visual and auditory sensation occurred; patients were instructed, if present, to report all of these after each stimulation trial was over. When the stimulus intensity was increased >10 mA without any positive motor symptoms or subjective perceptions, the absence of positive (e.g., tonic contraction) and negative (e.g., impairment of rapid alternating movements) tongue motor responses was confirmed, and a series of language batteries were administered, each lasting 3–5. This language mapping is described in detail elsewhere (Matsumoto et al., 2011; Usui et al., 2003). We judged the induced or impaired behaviors as significant only when the findings were reproducible (at least two trials) without afterdischarges. In cases of frequent afterdischarges, we decreased the stimulation intensity by 1–2 mA so that these did not occur. The majority of high-frequency ES was performed in a bipolar fashion (i.e., stimulation at two adjacent electrodes). In addition, we occasionally performed monopolar stimulation with reference to an electrode in the nonfunctional cortex to further localize the language areas for the clinical purpose.

2.3. Assessments of mirth and laughter-related facial muscle movements

Following every ES trial, if the patient spontaneously reported a feeling of mirth, the examiners (Y.Y., T.S.) inquired as to its presence and character. Since mirth is solely subjective, we judged the reported feeling as significant when the findings were reproducible (in at least two trials) without afterdischarges. In Patient 1, we also performed sham stimulation (i.e., stimulation at 0 mA intensity) to confirm that mirth was induced only by real ES. In order to reproducibly characterize mirth and its associated facial movements, additional trials were performed for research purposes. After the first subjective report of mirth, the stimulation intensity was increased gradually up to 15 mA in order to assess the language function.

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