Modulation of corticospinal activity by strong emotions evoked by pictures and classical music: a transcranial magnetic stimulation study

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Using transcranial magnetic stimulation and skin conductance responses, we sought to clarify if, and to what extent, emotional experiences of different valences and intensity activate the hand–motor system and the associated corticospinal tract. For that purpose, we applied a newly developed method to evoke strong emotional experiences by the simultaneous presentation of musical and pictorial stimuli of congruent emotional valence. We uncovered enhanced motor-evoked potentials, irrespective of valence, during the simultaneous presentation of emotional music and picture stimuli (Combined conditions) compared with the single presentation of the two modalities (Picture/Music conditions). In contrast, vegetative arousal was enhanced during both the Combined and Music conditions, compared with the Picture conditions, again irrespective of emotional valence. These findings strongly indicate that arousal is a necessary, but not sufficient, prerequisite for triggering the motor system of the brain. We offer a potential explanation for this discrepant, but intriguing, finding in the paper. *NeuroReport* 18:261–265 © 2007 Lippincott Williams & Wilkins.

Keywords: bimodal presentation of emotional pictures and music, corticospinal activity, emotion, transcranial magnetic stimulation, valence and intensity

Introduction

Classical theories of emotion and motivation propose a strong link between emotion, motivation, and behavior [1]. For example, seeing a disturbing stimulus (e.g. a snake) evokes fear, increased arousal in the autonomic nervous system [heart rate (HR), electrodermal activity], depletion of specific hormones, and flight or avoidance behaviors. In this frame of reference, emotion is strongly linked to motor output and one can conceive that emotions will automatically activate the motor areas. Interestingly, only a few studies have been published so far, which have implicitly or explicitly examined whether the motor cortex is indeed activated during emotional experience. Most of the studies reporting motor cortex activation during emotional experience have reported motor cortex activation as a byproduct of studies which have been designed to study other questions than the involvement of the motor cortex in emotion processing [2,3].

A direct or indirect involvement of the primary hand motor cortex in emotional processes has been suggested by only two transcranial magnetic stimulation (TMS) studies in which motor-evoked potentials (MEPs) measured for finger muscles were registered by stimulation of hot spots in the hand motor area while the participants were involved in some kind of emotional processing. The first study of this type [4] found increased MEPs of the left finger muscles during the imagination of sad thoughts and increased MEPs on the right finger muscles during happy thoughts. This study supports the approach–avoidance theory of Davidson [5], in which the left hemisphere controls approach and the right hemisphere controls avoidance behavior. A more recent study found enhanced MEPs only when a paired-pulse paradigm was used in which the supplementary motor area was activated shortly before M1. Using this protocol, the authors found increased MEPs only in situations when the participants decided whether a negative stimulus was presented or not. Interestingly, there was no modulation of corticospinal activation during emotion-related processing after prestimulation of the lateral premotor cortex and M1 [6]. The authors argue that the supplementary motor area provides a link between limbic structures and the motor system only during the processing of negative emotions.

Although the above-mentioned studies support the idea of a motor cortex involvement in emotion processing, there are nevertheless some important issues unanswered yet. For example, it is not known so far whether activation of the motor areas during emotional reactions depends on the intensity and/or valence of the stimuli-evoking emotions. Considerable evidence exists arguing for an automatic coupling between negative and threatening emotions and motor cortex activity because activation of an appropriate motor reaction in response to a threatening stimulus has survival value. On the other hand, the link between positive emotions (such as happiness) and motor behavior should be less strong because in evolutionary terms there is no direct survival value associated with a particular motor behavior related to positive emotions.

To clarify the mentioned questions, we examined whether, and to what extent, emotional experience of different valence and intensity activates the hand–motor system and the associated corticospinal tract. For that purpose, we used a newly developed method to evoke stronger emotional experiences than in conventional paradigms. The essence of this design is to present together musical and pictorial stimuli of congruent emotional valence known to evoke the strongest emotional reactions [7]. We hypothesize that the combined presentation of pictorial and musical stimuli with congruent emotional valence will evoke stronger motor cortex activation along with increased psychophysiological body reactions than the unimodal presentation of either visual or auditory emotional stimuli. Moreover, we further explored whether negative emotions will evoke stronger motor cortex activation than positive emotions.

Materials and methods

Study participants

Twenty-four healthy, consistently right-handed (measured using the Annett–Handedness questionnaire, [8]) female students (mean age 23.8 years, SD 3.3 years) of the University of Zurich were recruited to participate in the experiment. All had normal or correct-to-normal vision, were informed about the method and all of them gave written consent. The experiment was performed in accordance with standard safety guidelines, and the Ethics Committee of the University of Zurich gave approval for the study.

Transcranial magnetic stimulation and motor-evoked potential measurement

Study participants were seated 115 cm in front of a computer screen in a comfortable chair that included a chin rest and two head rests. The apparatus fixed the head to avoid head movements. The coil was placed tangentially on the scalp over the optimal spot to elicit MEPs in the right M abductor pollicis brevis (APB). Orientation was approximately perpendicular to the central sulcus. TMS was induced with a Magstim Rapid Stimulator (Magstim Company, Whitland, UK) and a 70-mm figure-eight coil (maximum magnetic field strength: 2.2 T, biphasic waveform). Before the experiment, the individual resting motor threshold was measured at the right APB by delivering TMS to the contralateral (left) primary motor cortex. It was defined as the minimum intensity needed for eliciting MEPs (transcranial MEPs) of at least 50 μV in amplitude (baseline to peak) in at least five out of 10 single TMS pulses when the muscle was completely relaxed. MEPs were recorded from the right APB muscle using gold cup surface electrodes (11 mm diameter) filled with contact gel in a belly tendon montage. To avoid high impedances, the skin was vigorously prepared with cleaning pads soaked in alcohol and abrasive gel. The electromyograph (EMG) signal was recorded with a conventional EMG amplifier and recorder using a bandpass of 20 Hz–3 kHz and stored in a PC for offline analysis. Audio EMG activity was monitored during the experiment to ensure that muscles were fully relaxed.

Experimental protocol

The basic principle of this experiment was to present a particular emotion condition for a duration of 70 s and to evoke 10 MEPs during each condition by stimulating the left hand motor cortex using TMS single pulses at 120% of the individual resting motor threshold. TMS single pulses were applied during the complete duration of the emotional conditions at interstimulus intervals varying randomly between 5 and 9 s (mean=7 s). Each MEP was recorded and subjected to further analysis. The experiment was designed as 3×3 repeated measurement design with three emotional valence conditions (Fear, Happy, Sad) and three modality conditions (Picture, Music, Combined).

Stimuli

The musical stimuli consisted of excerpts of exactly 70 s duration and were taken from the following classical orchestral pieces: (i) Gustav Holst: '*Mars, der Kriegsbringer*' from '*Die Planeten*', (ii) Samuel Barber, '*Adagio for Strings*', and (iii) Beethoven '*Symphonie no. 6*'. The musical piece from Gustav Holst was used because it evokes fear, the musical piece from Barber evokes sadness, and Beethoven's piece was used to evoke happiness. Several previously published papers from independent groups have shown that these musical pieces reliably evoke the different emotional states [7,9–11]. To prevent startle reflexes at the beginning of the presentation of the musical pieces, a fade-in procedure was used allowing a gradual increase in the intensity of auditory stimuli within the first second. A similar fade-out procedure was implemented at the end of the stimulus presentation to avoid offresponses. The musical pieces were presented via loudspeakers, which were situated on the right or left side in front of the participants and were presented with an individually adjusted comfortable listening level (between 70 and 80 dB).

Sixty pictures were chosen to evoke fear, sadness and happiness. Most of the pictures were taken from the International Affective Picture system (46 pictures). Most pictures have been used in pilot experiments and in former experiments of our group [7,9], and thus were evaluated on 9-point scales according to their valence and intensity. Low valence scores indicate negative valence whereas high scores indicate positive valence. Correspondingly, low values on the intensity scale indicate low intensity or arousal and high values indicate high intensity or arousal. According to the previous experiments, these three picture categories were judged according to the valence scale as follows: (i) fear=2.2, (ii) sadness=3.3, and (iii) happiness=7.8, and according to the intensity scale as follows: (i) fear=6.5, (ii) sadness=5.2 and (iii) happiness=6.1. The pictures were presented on a 17-inch computer screen situated 115 cm in front of the participants. Each picture was presented for 7 s. To conform to the presentation duration of the musical pieces, 10 pictures evoking the same emotion were sequentially presented both in the Combined and in the Picture conditions.

Pictures and music were presented in three conditions: (i) in the Picture condition only the pictures were presented,

(ii) in the Music condition only the musical stimuli were presented, and (iii) in the Combined condition pictures and music congruently evoking the same emotion were presented simultaneously. To exclude order effects, the presentation of the three conditions and the order of the picture presentation were carefully pseudorandomized. Moreover, the pictures were only presented once during the whole experiment. Thus, to avoid selection effects, half of the participants experienced one part of the pictures in the Picture conditions, whereas the other half of the participants experienced the same part of the pictures in the Combined conditions and accordingly, the opposite was true for the other part of the chosen pictures. The Presentation software (Neurobehavioural Systems, version 0.70, 2003; Albany, California, USA) was used to control stimuli presentation. Thus, we employed a fully randomized two factorial experiment with Valence and Modality as independent variables.

Psychophysical measurements

HR and skin conductance response (SCR) were collected using a commercially available device (PAR-PORT manufactured by Hogrefe Company, Göttingen, Germany). For SCR recording, electrodes were attached to the thenar and hypothenar areas on the palm of the left hand. Quantification of SCRs entailed measurement and summation of the SCR amplitude during the 70 s experimental period.

Psychometrical measures

After each experimental condition, participants gave two affective ratings via button-press on a computer-based 5-point scale (valence and involvement ratings, ranking from ‘1=negative or weak’ to ‘5=positive or strong’). The involvement rating measured how strongly the participants were involved or engaged in the different emotional experiences.

Statistical analysis

The 10 MEPs obtained during each experimental condition were averaged to a mean MEP, representing the corticospinal activity during each condition. These values were used as dependent variable and subjected to a two-way repeated analysis of variance (ANOVA) with two repeated measurements factors. In addition, a stepwise multiple regression analysis was computed for repeated measurements [12]. In this analysis, MEPs were used as dependent variables and all other variables as independent variables (psychometric measures, psychophysiological measures, and the effect-coded variables representing the experimental conditions). Results were considered as significant at the level of $P<0.05$ and as effect size measure ETA^2 is reported. In case of a significant multivariate effect, *post hoc* paired *t*-tests were computed using the Bonferroni correction according to Holm [13].

Results

Analysis of psychometrical data: valence and involvement scales

Repeated-measures ANOVA regarding the Valence scale demonstrated highly significant main effects and a significant interaction between both independent variables (Valence: F(2,22)=67.9, $P<0.001$, $\mathrm{ETA}^2=0.86$; Modality: F(2,22)=6.46, $P<0.01$, $\mathrm{ETA}^2=0.37$; Valence × Modality: F(4,20)=7.57, $P<0.001$, $\mathrm{ETA}^2=0.60$), indicating that the participants clearly differentiated on a 5-point scale between the negative and positive emotions. The interaction was qualified by the fact that the participants experienced the different emotions at their most extreme in the Combined conditions, intermediate in the Picture conditions and lowest in the Music conditions. Thus, they rated the Happy condition most positive and the Sad and Fear condition most negative when congruent emotional music was simultaneously presented, whereas the opposite was true for the Music alone conditions (see Fig. 1c). Repeated-measures ANOVA regarding the involvement scale showed two main effects (Valence: F(2,22)=6.34, $P<0.01$, $\mathrm{ETA}^2=0.37$; Modality: F(2,22)=4.27, $P<0.05$, $\mathrm{ETA}^2=0.28$), indicating increased involvement experience in the Sad emotional conditions compared with the Fear conditions as well as enhanced involvement experience in the Combined compared with both the Music and Picture conditions (see Fig. 1d).

Analysis of psychophysical data: skin conductance response and heart rate

Analysis of the HR data using a two-way repeated-measurements ANOVA revealed no significant main effect for valence or a significant interaction between modality and valence. We, however, observed a significant main effect of modality (F(2,21)=3.54, $P<0.05$, $\mathrm{ETA}^2=0.25$), which was qualified by increased HR in the Music conditions compared with the Picture conditions. For SCR, we only observed a significant main effect for modality (F(2,21)=6.03, $P<0.01$, $\mathrm{ETA}^2=0.37$), which was qualified by larger SCR amplitudes during presentation of the Combined and Music conditions compared with the Picture conditions (see Fig. 1b).

Analysis of transcranial magnetic stimulation data (motor-evoked potentials)

The two-way repeated measures ANOVA with MEP amplitudes as dependent variables revealed a highly significant main effect for Modality (F(2,20)=5.57, $P<0.01$, $\mathrm{ETA}^2=0.34$). The main effect of Valence (F(2,22)=1.63, $P=0.22$, $\mathrm{ETA}^2=0.13$) and the interaction effect of Valence × Modality were not significant (F(4,20)=0.19, $P=0.94$, $\mathrm{ETA}^2=0.04$). Subsequent post-hoc tests revealed larger MEP amplitudes during presentation of the Combined conditions compared with both the Picture ($P=0.014$) and Music ($P=0.003$) conditions. This difference was apparent for all emotion conditions (Fear, Sadness, and Happiness, see Fig. 1a). The additionally calculated multiple regression analysis revealed that Modality was the only predictor explaining the variability of MEP amplitudes ($t=3.97$, $R^2=0.26$). No other predictor turned out to explain MEP variability significantly.

Discussion

This study was designed to explore two different questions. First, we were interested in evaluating whether emotions of different valence (irrespective of presentation modality) evoke different corticospinal activations within the motor system. Second, extending previous work of our group, we explored whether the combined presentation of pictures and music evoking congruent emotions elicits stronger corticospinal activity, indicated by increased MEP amplitudes.

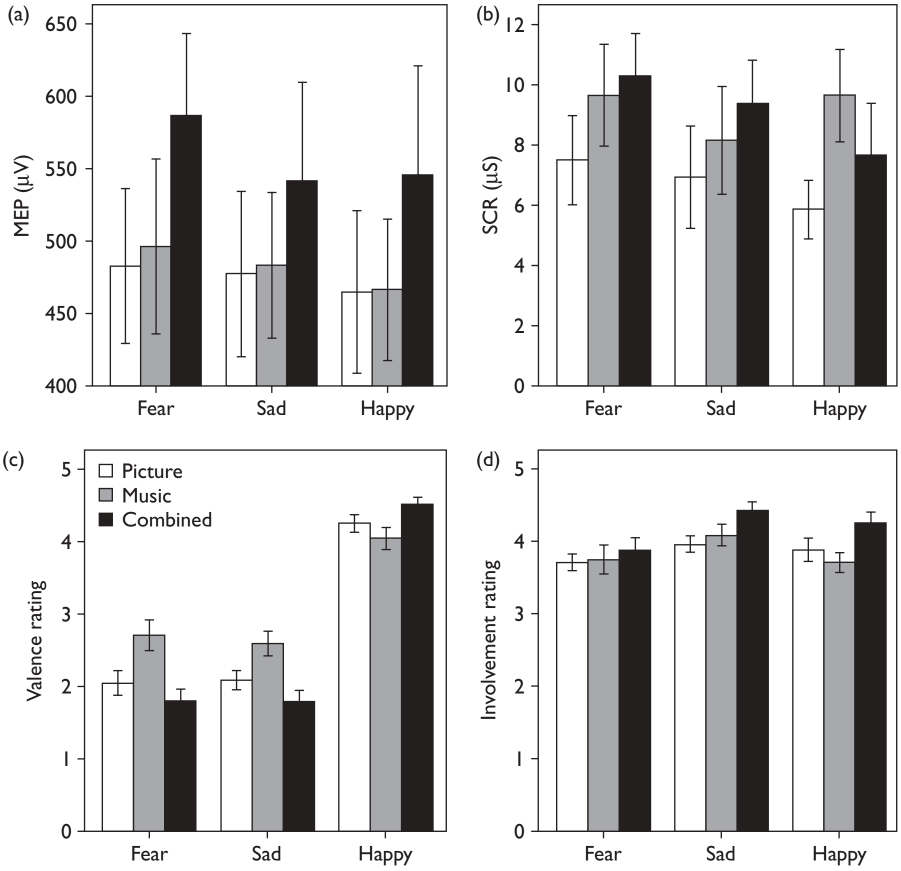

Fig. 1 Means (±SEM) of motor-evoked potentials (MEPs) (a), skin conductance response (SCRs) (b), Valence ratings (c) and Involvement ratings (d) for all three modality conditions (Picture, Music, Combined) and all three emotional valence conditions (Fear, Sad and Happy).

Before we discuss the main findings of our study with regard to corticospinal activity, we will briefly describe the psychometrical and psychophysiological findings.

As anticipated, the participants clearly differentiated the emotional valence for all presentation conditions. More interesting for the present experiment is the finding that the participants experienced the different emotions at their most extreme in the Combined conditions, intermediate in the Picture conditions and lowest in the Music conditions, that is they rated the Happy condition most positive and the Sad and Fear condition most negative when congruent emotional Music and Pictures were simultaneously presented. This effect nicely replicates findings of previous experiments of our laboratory using the same emotional stimuli [7,9]. A further similarity with our previous work is the finding of increased SCR during the Combined and Music conditions. In addition, we found that the participants indicated increased involvement experience during the Combined compared with both the Music and Picture conditions.

The main focus of our study was to explore whether the motor system is differently activated during the different experimental conditions. We found no difference between the MEPs obtained during the presentation of emotional stimuli of different valence. Thus, our hypothesis that emotions with negative valence (e.g. Fear) would automatically evoke the motor system because fight or flight-related movements are initiated was not substantiated. We, however, measured the strongest MEP amplitudes during the combined presentation of pictorial stimuli and musical phrases of congruent emotional valence compared with the presentation of pictures or musical stimuli alone. But why is the corticospinal activity increased during the Combined conditions?

The first conceptual candidate to describe this facilitation effect is general arousal affecting a distributed cortical and subcortical network including the motor areas. From further experiments of our group and others, it is known that strong emotional experience (as found in the Combined conditions) is accompanied by neural activations in distributed brain areas associated with the generation and control of emotions (e.g. amygdala, hypothalamus, etc.) and cognitions (frontal and parietal cortex) [9,14–18]. The fact that distributed cortical activation increases during emotional experiences has been shown in several electroencephalographic studies [5,7]. In these papers, no specific emphasis was placed to explicitly register activation from the motor cortex. Substantial activation increases (indexed as α-power desynchronisation), however, occur in the vicinity of motor areas at electrode positions C3, C4, F3, or F4. Facilitation of MEPs with TMS delivered to the primary hand motor cortex have also been demonstrated during deception [19]. Finally, an unspecific increase of activation in the motor system during emotional experience is supported by several studies reporting that the peripheral motor system increases activation during emotional experience. For example, EMG activity in many muscles (head, arms or foot) increases their activation during emotional experience [20,21]. Most of these activation increases in various muscles correlate with enhanced SCR and HR responses arguing for an unspecific tonic increase of activation affecting the entire brain, which might result in a distributed increase of cortical activation.

The hypothesis of an unspecific tonic increase of activation in the primary motor system owing to increased arousal experiences, however, cannot explain why we did not find a similar increase in corticospinal activity in the Music alone conditions despite a similar or even slightly enhanced arousal level (measured with SCR and HR) in comparison with the Combined conditions. Thus, it seems that an increase in arousal is a necessary, but not yet sufficient, prerequisite to increase the activation in the motor system of the brain. What other mechanism could trigger activation of the corticospinal output system of the brain? We hypothesize that the dissociation between the arousal measurements and the corticospinal activity in the Music alone conditions supports the notion that emotional musical excerpts activate an internal mode of brain function. This internal mode is characterized by cognitive and emotional processes revolving around the participant's internal state instead of current external events or circumstances [7,22,23]. In contrast, visual stimuli, sound stimuli (e.g. the crying of a baby), as well as the combination of pictures and music automatically activate emotional perception processes characterized by focussing attention to external events – probably owing to the fact that these stimuli are more important to evaluate changes in the environment, whereas musical stimuli alone have no direct evolutionary connection to the external world. Therefore, whereas both the Combined conditions and the Picture conditions seem to activate a similar (external) mode of brain function (however, with different arousal levels), the Music conditions probably activate a different (internal) mode of brain function. Accordingly, the motor system preparing the participant to react adequately to external events or circumstances shows diminished activations, leading to reduced corticospinal activity indexed in our study by reduced MEPs in the Music alone compared with the Combined conditions. In this context, it is interesting to note that the involvement rating is in good agreement with the MEP findings, that is the participants reported to be less involved in conditions with low corticospinal activity (including Music conditions and Picture conditions) and more involved in conditions with strong corticospinal activity (including the Combined conditions). Thus, in spite of a similar vegetative arousal level in the Combined and Music alone conditions, participants rated the Music conditions as significantly less involving, in our opinion at least partly owing to decreased activation of the output system of the brain.

Conclusion

Taken together, our study confirmed that the immersive feeling of emotions as elicited by the combined presentation of Music and Pictures facilitates corticospinal activity of the hand–motor system. This enhanced corticospinal activation was accompanied by strong reactions of the vegetative system (SCR) and by stronger subjective expressions of emotional feelings. Moreover and most interesting, this is the first emotional study showing that motor cortex activation is not only due to a general, unspecific increase in arousal, but rather also owing to a specific increase of arousal in situations when the focus of attention is strongly directed to external events and circumstances.

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