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Emotion facilitates action: A transcranial magnetic stimulation study of motor cortex excitability during picture viewing

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Abstract

Emotional stimuli capture attention, receive increased perceptual processing resources, and alter peripheral reflexes. In the present study, we examined whether emotional stimuli would modulate the magnitude of the motor evoked potential (MEP) elicited in the abductor pollicus brevis muscle by transcranial magnetic stimulation (TMS) delivered to the motor cortex. The electromyogram (EMG) was recorded from 16 participants while they viewed six blocks of pleasant, neutral, and unpleasant images; 36 TMS pulses at increasing intensities were delivered during each block. The TMS-induced MEP was reliably larger while participants viewed pleasant and unpleasant compared to neutral images. There were no differences in the pre-TMS EMG activity as a function of emotional stimuli. Thus, viewing arousing stimuli, regardless of valence, increased motor cortex excitability. Implications and directions for future research are discussed.

Descriptors: TMS, IAPS, emotion, cortical excitability, motivation

A number of studies have utilized the human startle eyeblink reflex to better understand emotional processing (Lang, Davis, & Öhman, 2000; Vrana, Spence, & Lang, 1988). The startle eyeblink reflex is typically measured as the magnitude of a blink, recorded from the orbicularis oculi, in response to a sudden acoustic stimulus. The startle eyeblink response has been shown to be potentiated when participants view threatening stimuli, indicating that defensive reflexes are primed by aversive stimuli (Lang et al., 2000).

Reflexes that are not inherently defensive, however, appear to be potentiated by both appetitive and aversive emotional stimuli. Two studies found that spinal reflexes were enhanced while participants viewed both pleasant and unpleasant stimuli (Bonnet, Bradley, Lang, & Requin, 1995; Both, Everaerd, & Laan, 2003). For instance, Both et al. recorded the electromyogram (EMG) in the soleus muscle of the lower leg following a hammertap at the heel tendon, and found that this response was larger when participants viewed appetitive and aversive compared to neutral images.

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Collectively, these data suggest that emotional stimuli may prime or facilitate action, consistent with the view that emotional processing might mobilize the body for action (Frijda, 1986; Lang, 1993). The interface between emotion and action presumably involves limbic structures directly or indirectly activating motor areas of the brain (Mogenson, Jones, & Yim, 1980), and data from nonhuman studies suggest that this may involve interconnections between the amygdala, anterior cingulate cortex, and supplementary motor area (Devinsky, Morrell, & Vogt, 1995; Luppino, Matelli, Camarda, & Rizzolatti, 1993; Morecraft & Van Hoesen, 1992; Oliveri et al., 2003). Consistent with this possibility, some studies have reported increased activity in motor areas of the brain during emotional processing using neuroimaging techniques (Bremner et al., 1999; Rauch et al., 1996).

Transcranial magnetic stimulation (TMS) allows one to directly investigate cortical excitability by stimulating primary motor areas of the brain and quantifying the magnitude of the response via the motor evoked potential (MEP). TMS involves a noninvasive magnetic pulse that is discharged at the scalp surface; underneath the scalp, the magnetic pulse induces electric fields that cause neurons to depolarize (Bohning, 2000). By selectively placing the TMS coil over particular areas of the motor cortex, it is possible to elicit specific motor responses. The degree of motor output is sensitive to stimulation intensity such that MEP amplitudes become larger as TMS pulse intensity increases

(Capaday, 1997; Devanne, Lavoie, & Capaday, 1997; Hess, Mills, & Murray, 1987; Kiers, Clouston, Chiappa, & Cros, 1995). It has been shown that voluntary activation of target muscles increases the magnitude of the TMS-elicited MEP (Hess, Mills, & Murray, 1986; Hess et al., 1987; Kischka, Fajfr, Fellenberg, & Hess, 1993; Ravnborg, Liguori, Christiansen, Larsson, & Sørensen, 1992). Additionally, preparation to act and imagined movement produce a similar increase in TMS-elicited MEP magnitude (Fadiga et al., 1999; Rossi, Pasqualetti, Tecchio, Pauri, & Rossini, 1998; Strafella & Paus, 2000). These results suggest that variation in the MEP following TMS might also be sensitive to the facilitatory effect of emotion on action. If so, these results would indicate that processing emotionally salient information alters central measures of cortical excitability in the motor cortex.

Using TMS, one study found that stimulating the supplementary motor area (SMA) prior to motor cortex stimulation led to an increase in MEP amplitude, but only in the context of responding to unpleasant compared to neutral stimuli (Oliveri et al., 2003). Oliveri et al. did not, however, find a direct effect of unpleasant emotional stimuli on motor cortex excitability. In the present study, we sought to further examine whether viewing emotional stimuli would increase motor cortex excitability by presenting pleasant, neutral, and unpleasant pictures in a blocked design. We hypothesized that both pleasant and unpleasant pictures would increase cortical excitability compared to neutral pictures based on the general notion that appetitive and aversive stimuli prompt action dispositions to approach and withdraw, respectively (however, see Larsen, Norris, and Cacioppo, 2003, and Harmon-Jones, 2004, for exceptions to this dichotomy). That is, we predicted that TMS-induced MEP amplitude would be increased while participants viewed pleasant and unpleasant compared to neutral pictures, and that there would be no differences in MEP amplitude between pleasant and unpleasant picture viewing. To test this hypothesis, we measured EMG activity following TMS pulses while participants viewed blocks of pleasant, neutral, and unpleasant images taken from the International Affective Picture System (Lang, Bradley, & Cuthbert, 1999). Because MEP amplitudes are larger if TMS is delivered during the active contraction of muscles (Hess et al., 1986), it is important to ensure that any facilitatory effects of emotion are not simply attributable to increased muscle tension during emotional picture viewing. To examine this possibility, we also evaluated the amount of pre-TMS EMG activity across blocks of pleasant, neutral, and unpleasant pictures.

Method

Participants

Eighteen participants (11 male) recruited from the Medical University of South Carolina community (6), and other local colleges (12) participated in the current experiment for either $20.00 or extra academic credit. Data from 2 participants were not used: 1 participant (female) discontinued half-way through the experiment after she reported feeling faint, and another participant's (male) data were not used because of technical malfunction. Self-reported valence and arousal ratings were not collected from two participants (1 male) because of experimenter error. Thus, TMS-induced EMG activity was recorded from 16 participants (10 male); picture-rating data were collected from 14 (8 male) of these participants.

Stimulus Materials

One hundred twenty pictures were selected from the International Affective Picture System (IAPS; Lang et al., 1999); of these, there were 40 unpleasant scenes (e.g., threat and mutilation), 40 pleasant scenes (e.g., smiling families, sporting events, nudes), and 40 neutral scenes (e.g., household objects, leaves, trees).[1] The task was administered on a Pentium I class computer, using Presentation software (Neurobehavioral Systems, Inc.) to control the presentation and timing of all stimuli. Each picture was displayed in color and occupied the entirety of a 20-in. monitor placed approximately 25 cm in front of the participant; at this viewing distance, each picture occupied nearly 70° of visual angle horizontally and vertically.

Magnetic Stimulation of the Brain

Focal TMS was applied with a figure-eight-shaped stimulation coil (mean diameter of each lobe was 8 cm) that was powered by a Magstim 200+stimulator (Magstim, Whitland, Dyfed, UK) that delivered monophasic pulses (maximum magnetic flux density of 2.2 T). The center of the figure eight magnet was initially positioned 5 cm lateral to the vertex on the interauricular line with the handle in line with the parasagittal plane. TMS coil placement was then optimized by delivering pulses while examining the resulting MEP displayed through Spike2 software (Version 5; Cambridge Electronic Design).

EMG Recording and Measurement

The EMG was recorded using two pregelled Nicolet 19 × 44 mm Ag-AgCl disposable electrodes; these electrodes were placed over the region of the abductor pollicus brevis (APB) belly and associated tendon of the right hand. One electrode was placed over the belly of the APB muscle in parallel to the direction of the muscle fibers; the second electrode was placed approximately 3 cm away on the tendon. Activity in the APB muscle was chosen as the dependent measure of cortical excitability for several reasons. First, when the appropriate motor area is stimulated with TMS, the thumb abductor muscle contracts in a way that is clearly different from the contraction of nearby wrist or hand muscles; thus, it is possible to verify visually that TMS is being delivered at a consistent location. Second, the APB muscle is often used in TMS studies that record MEP responses as a function of stimulation intensity because muscles with strong corticospinal projections, such as the APB, have lower motor thresholds and steeper MEP recruitment compared to muscles with weaker corticospinal projections, such as biceps or lower limb muscles (Brouwer & Ashby, 1990). Additionally, a 38 × 55 mm pregelled Ag-AgCl ground electrode was placed on the back of the right hand. EMG activity was filtered using the Micro 1401 MK II and CED 1902 signal conditioner between 0.5 and 1000 Hz, with a 60-Hz notch filter, and was digitized at 5 kHz (Cambridge Electronic Design). The digitized signal was further

[1]The number of the IAPS pictures used were the following: pleasant (1601, 2000, 2070, 2080, 2091, 2092, 2165, 2311, 2340, 4002, 4180, 4220, 4290, 4532, 4572, 4608, 4658, 4659, 4660, 4664, 4800, 4810, 5470, 5621, 5626, 5628, 7325, 8021, 8032, 8080, 8200, 8210, 8280, 8320, 8330, 8370, 8400, 8465, 8490, 8540), neutral (2190, 2480, 2570, 2840, 2880, 5390, 5500, 5510, 5532, 5534, 5731, 5740, 5800, 5900, 7000, 7002, 7004, 7006, 7009, 7010, 7025, 7030, 7034, 7035, 7040, 7040, 7060, 7080, 7090, 7100, 7140, 7150, 7175, 7190, 7217, 7224, 7233, 7235, 7491, 7950), and unpleasant (2800, 2900, 3051, 3102, 3110, 3261, 3530, 3550, 6230, 6242, 6250, 6260, 6313, 6350, 6370, 6510, 6540, 6560, 6570, 6571, 6821, 9040, 9050, 9253, 9300, 9400, 9405, 9410, 9421, 9433, 9490, 9520, 9530, 9570, 9800, 9810, 9910, 9911, 9920, 9921).

filtered using a digital filter with a − 3 dB cutoff frequency of 25 Hz and transition band of 13 Hz.

Traditionally, resting motor threshold (rMT) is defined as the stimulation intensity that elicits a MEP response (i.e., a peak-to-peak amplitude exceeding 50 μV) with .50 probability over 10 trials. In the present study, rMT was defined using a best parameter estimation by sequential testing (BEST-PEST) method (Awiszus, 2003) that dynamically adjusts TMS intensity based on whether or not a 50-μV MEP amplitude response occurs at a given stimulation intensity (Mishory et al., 2004).

EMG data were visually inspected to ensure that the scoring algorithm quantified appropriate responses. Motor MEP amplitude elicited was quantified off-line with Spike2 software and scored as the peak-to-peak amplitude of the maximal EMG response. Pre-TMS EMG activity was quantified as the root mean square amplitude of EMG activity in the 900-ms time period preceding each TMS pulse.

In all cases, the interpulse interval (IPI) varied randomly between 3 and 5 s to avoid conditioned responses to the sound of the TMS device. MEP amplitudes were statistically evaluated using SPSS (Version 10.1) General Linear Model software, with Greenhouse–Geisser correction applied to p values associated with repeated measures comparisons with multiple degrees of freedom.

Experimental Procedure

After a brief description of the experiment and demonstration of TMS, participants inserted earplugs and were seated; the experimental apparatus was adjusted to a height to allow each participant to comfortably place his or her chin in a chin rest. Once the TMS coil was placed to elicit maximum EMG activity from the APB muscle, the TMS coil and the participant's head were secured in an immobile frame. The participant was then instructed to relax. The participant's right arm was placed in an immobile cast to reduce movements during the experiment; the participants rested their arm in the cast with their palm facing upward for the duration of the experiment. Spike2 software was then used to determine the participant's rMT as described above. Next, 36 TMS pulses were delivered at six intensities beginning at 5% (of the maximum stimulator output of 100) below rMT and increasing in increments of 5% until reaching an intensity of 20% above rMT; six pulses were delivered at each of these six intensity levels. The MEP magnitude for a given stimulation intensity was quantified as the median MEP response.

This first stimulation block served as an initial recording of this progression from rMT − 5 to rMT+20, and participants did not view any pictures but had their eyes open. In each of the next three blocks, pleasant, neutral, or unpleasant pictures were presented. Participants were simply instructed to view the pictures; in each block, 36 TMS pulses were delivered as intensity systematically increased from rMT − 5 to rMT+20 as described above. Within each block, pictures were presented for 3000 ms with no interstimulus interval; their order was determined randomly. After each picture was presented one time, the stimuli were rerandomized and picture presentation continued until the 36 TMS pulses had been delivered. The order of the pleasant, neutral, and unpleasant blocks was determined randomly; no order occurred more frequently than others. After these three blocks, rMT was once again determined using the BEST-PEST method, and the final three blocks (again presented in random order) began using the same pictures that were used in the first three blocks. The initial rMT was utilized to determine stimulation intensity in the first three blocks, whereas the second rMT was utilized to determine stimulation intensity in the last three blocks. The TMS portion of the experiment lasted approximately 20 min.

Next, the TMS coil was disconnected and participants were told that they could sit back in their chair; at this point, participants once again viewed each of the 120 IAPS pictures and were instructed to rate them using the self-assessment manakin (Lang, 1980). Pictures were presented in a random order for 3000 ms each; after picture offset, an analog valence scale was displayed that depicted five characters who ranged from happy to unhappy; below this scale were the numbers 1 through 9 (1 corresponded to the happiest figure, 3 to next most happy figure, and 2 was located between the previous two, and so on). Participants were told to rate each picture on this scale based on how pleasant or unpleasant it made them feel. After participants rated a given picture along the valence dimension, another analog scale was presented that depicted five characters who appeared to have a very strong visceral response to no visceral response; again, the numbers 1 through 9 were presented below this scale, and participants were told to rate the picture, but this time based on the *strength* of their emotional response to the picture. On both the arousal and valence dimension, a score of 5 represented the midpoint between the two extreme ratings, and participants were encouraged to use any point on the scale even if it fell between two of the five figures on the analogue scales.

Results

Behavioral Data

The average valence ratings for pleasant, neutral, and unpleasant IAPS pictures were 3.36 ($SD = 0.64$), 4.92 ($SD = 0.21$), and 7.52 ($SD = 0.49$),[2] respectively; a repeated measures ANOVA confirmed that these valence ratings differed significantly from one another, $F(2,28) = 296.99$, $p < .001$. All post hoc paired-sample t tests were significant, $t(14) > 10$ in all cases, $ps < .001$, indicating that these pictures types were rated as reliably different from one another on the valence dimension. Men and women did not differ from one another on valence ratings of neutral, $t(13) = 0.47$, $p > .60$, or unpleasant, $t(13) = 0.32$, $p > .75$, pictures; however, men rated pleasant pictures more positively than women, $t(13) = 2.70$, $p < .05$.[3]

The mean participant ratings of arousal for the pleasant, neutral, and unpleasant pictures were 6.33 ($SD = 1.35$), 8.40 ($SD = 1.07$), and 5.02 ($SD = 1.79$), respectively. These ratings of arousal differed significantly from one another, $F(2,28) = 62.84$, $p < .001$. Post hoc paired-sample t tests confirmed that both pleasant and unpleasant pictures were rated as more arousing than neutral pictures, $t(14) = 10.71$, $p < .001$, and $t(14) = 9.19$, $p < .001$, respectively; in addition, unpleasant pictures were rated as more arousing than pleasant pictures, $t(14) = 4.05$, $p < .001$. Men and women did not differ from one another in terms of their arousal ratings of pleasant, neutral, and unpleasant pictures, all p values $> .50$.

EMG Data

The mean rMT (as a percentage of maximum stimulator output) prior to the first block was 60.38 ($SD = 8.00$); prior to the second

[2]These means are nearly identical to those reported in other studies of the LPP (Cuthbert et al., 2000; Keil et al., 2002).

[3]Similar gender differences have been reported in the literature and may have to do with the fact that the pleasant pictures used depicted more female than male nudity (Lang, Greenwald, Bradley, & Hamm, 1993).

block, the mean rMT was 59.31 ($SD = 8.19$). These values did not differ from one another, $t(15) = 1.20$, $p > .25$, and rMT prior to the first and second block were highly correlated, $r = .91$, $p < .001$. The median MEP responses during the first block (no picture condition) from rMT − 5 to rMT+20 were 2.57 μV ($SD = 1.60$), 4.80 μV ($SD = 4.36$), 22.02 μV ($SD = 25.92$), 55.44 μV ($SD = 78.09$), 120.43 μV ($SD = 133.43$), and 207.29 μV ($SD = 172.15$).

The median MEP amplitude at each level of TMS intensity during pleasant, neutral, and unpleasant picture viewing are presented in Figure 1. A 3 (Picture Type) × 2 (Experiment Half) × 6 (TMS Intensity) repeated measures ANOVA was performed on median EMG response. Consistent with previous data, MEP amplitude increased as a function of TMS pulse intensity, $F(5,70) = 24,84$, $p < .001$. Importantly, the magnitude of the MEP varied as a function of Picture Type, $F(2,28) = 4.43$, $p < .05$. Although it appears in Figure 1 as if the influence of Picture Type on MEP amplitude became larger as stimulation intensity increased, the interaction between Picture Type and TMS Intensity did not approach significance, $F(10,140) = 1.09$, $p > .35$. Finally, MEP amplitude did not vary as a function of Experiment Half, $F(1,14) < 1$; other two- and three-way interactions involving Experiment Half did not reach significance.

To further examine the effect of Picture Type on MEP amplitude, post hoc paired-sample t tests were conducted; Figure 2 presents the mean MEP amplitude observed during pleasant, neutral, and unpleasant picture viewing collapsing across levels of stimulation intensity. Consistent with the impression from Figure 2, MEPs were larger when participants viewed unpleasant compared to neutral pictures, $t(15) = 2.95$, $p < .01$; similarly, MEPs were reliably larger when participants viewed pleasant compared to neutral pictures, $t(15) = 3.01$, $p < .01$. MEP amplitude during pleasant and unpleasant picture viewing did not differ, $t(15) = .53$, $p > .60$. The increased MEP elicited while participants viewed pleasant and unpleasant compared to neutral pictures was comparable in men and women, $t(14) = 1.06$, $p > .30$ and $t(14) = 1.10$, $p > .25$, respectively.

Pre-TMS EMG Activity

TMS-evoked MEPs are increased when muscles are contracted (Hess et al., 1986, 1987; Kischka et al., 1993; Ravnborg et al., 1992). Thus, it is possible that the observed modulation of MEP amplitude during emotional picture viewing could be due to an increase in baseline EMG activity when pleasant and unpleasant pictures were presented. To explore this possibility, pre-TMS EMG magnitude was evaluated with a 3 (Picture Type) × 6 (TMS Intensity) × 2 (Experimental Half) repeated measures ANOVA. Importantly, pre-TMS EMG activity did not vary as a function of Picture Type, $F(2,30) = 1.37$, $p > .25$, and Picture Type did not interact with TMS Intensity, $F(10,150) < 1$, or Experimental Half, $F(2,30) = 1.14$, $p > .30$; the three-way interaction between Picture Type, TMS Intensity, and Experimental Half also did not approach significance, $F(10,150) < 1$. This analysis did reveal a trend toward greater EMG activity at higher TMS intensities, $F(5,75) = 3.38$, $p < .10$, which was qualified by a TMS Intensity × Experiment Half interaction, $F(5,75) = 3.24$, $p < .05$. EMG activity did not vary as a function of stimulation intensity in the first half of the experiment, $F(5,75) = 1.01$, $p > .35$; however, there was a significant linear effect of stimulation intensity in the second half of the experiment, $F_{lin}(1,15) = 7.89$, $p < .05$.

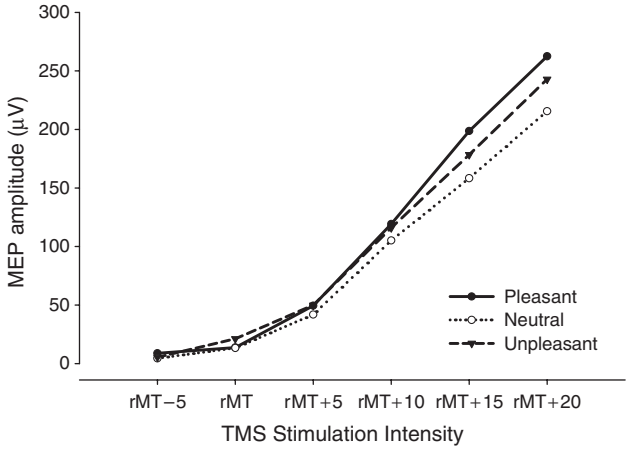

Figure 1. Median EMG response while participants viewed pleasant, neutral, and unpleasant pictures at each level of TMS intensity relative to each participant's resting motor threshold (rMT).

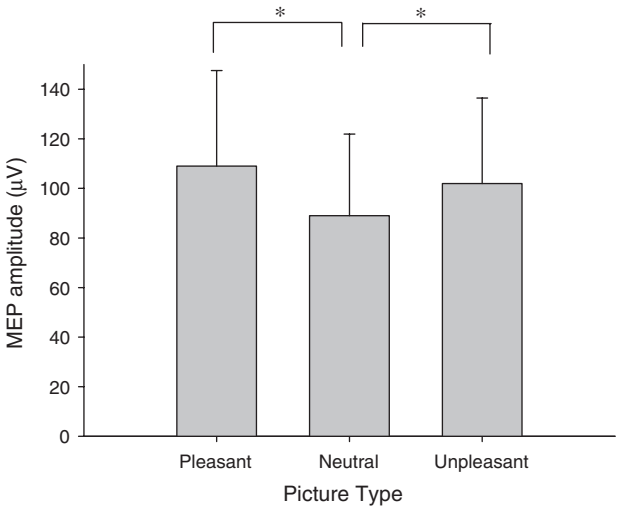

Figure 2. Mean EMG response while participants viewed pleasant, neutral, and unpleasant IAPS pictures, collapsing across TMS stimulation intensity level (error bars represent ± 2.13 standard errors, the 95% confidence interval; *$p < .01$).

Relationship between Self-Report and EMG Data

To determine whether the emotional modulation of cortical excitability was related to individual differences in how the IAPS pictures were rated, the average valence and arousal ratings (pleasant minus neutral and unpleasant minus neutral) for each participant were correlated with the magnitude of the emotion-modulated MEP (pleasant and unpleasant minus neutral); correlations were calculated on the subset of 14 participants who rated the IAPS pictures. The increased MEP elicited during pleasant picture viewing was unrelated to both valence, $r = -.09$, $p > .55$, and arousal, $r = .25$, $p > .35$, ratings of pleasant pictures; similarly, the increased MEP elicited during unpleasant picture viewing was unrelated to valence, $r = .23$, $p > .40$, and arousal, $r = .52$, $p > .05$, ratings of unpleasant pictures. Thus, the emotion-modulated MEP amplitude did not

vary systematically as a function of participants' arousal and valence ratings of these pictures.

Discussion

To our knowledge, this is the first study to report direct effects of emotional processing on a centrally mediated measure of motor cortex excitability. Specifically, the present study found that MEP amplitude varied as a function of emotional stimuli: When participants viewed pleasant and unpleasant pictures, MEP amplitudes following TMS pulses were larger than when participants viewed neutral pictures. Functionally, this effect is similar to MEP modulation following instructions to prepare for movement (Hoshiyama et al., 1997) and during imagined movement (Fadiga et al., 1999; Rossi et al., 1998), and these data provide evidence that motor cortex excitability is also sensitive to emotional processing.

Importantly, the present study did not find greater EMG activity in the pre-TMS period during the pleasant and unpleasant compared to neutral blocks; these data highlight the distinction between cortical excitability and motor activity, and argue against the possibility that MEP increases during emotional picture viewing simply indexed an increased response attributable to muscle tension (Hess et al., 1986, 1987; Kischka et al., 1993; Ravnborg et al., 1992). Nonetheless, it is certainly possible that emotional stimuli elicited corticospinal excitation that was not directly reflected by increased surface EMG activity, for example when cortical or spinal excitatory effects were subliminal.

Because increased MEPs were observed during both pleasant and unpleasant picture viewing, these data suggest that both appetitive and aversive visual stimuli modulate motor cortex excitability. This effect did not vary reliably as a function of TMS pulse intensity; however, the effect did appear somewhat larger as TMS pulse intensity increased. The fact that MEP amplitude is less variable at higher TMS intensities (Kiers, Cros, Chiappa, & Fang, 1993) may account for this trend toward larger effects at higher TMS intensities.

The fact that emotional stimuli elicit increased neural activity has been documented with fMRI (Bradley et al., 2003), PET (Lane et al., 1997), and event-related potentials (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000). In addition, emotional stimuli have been shown to modulate the magnitude of both the defensive startle eyeblink reflex (Lang et al., 2000) and spinal tendinous reflex (Bonnet et al., 1995; Both et al., 2003). Thus, the present data fit well within this body of studies, and indicate that motor cortex excitability is another index of how emotional processing modulates the activity of action output systems. Based on existing human and nonhuman studies, it stands to reason that this facilitation may depend on interconnections between areas such as the amygdala, anterior cingulate cortex, and supplementary motor area (Bremner et al., 1999; Devinsky et al., 1995; Luppino et al., 1993; Mogenson et al., 1980; Morecraft & Van Hoesen, 1992; Oliveri et al., 2003; Rauch et al., 1996). Future research might further explore the neuroachitechture supporting this effect by combining TMS and fMRI methodologies.

It should be noted that a previous study only reported indirect effects of unpleasant pictures on motor cortex excitability (Oliveri et al., 2003). This study found that MEP amplitudes were larger if the SMA was stimulated prior to the motor cortex on trials involving unpleasant compared to neutral pictures; however, the facilitatory effect of unpleasant pictures was not observed when the motor cortex was stimulated in the absence of prior SMA stimulation (Oliveri et al., 2003). There are several methodological differences between the studies that might account for this discrepancy. First, the present study presented pictures in a blocked design, and subjects did not have to perform a task. On the other hand, the Oliveri et al. study involved random presentation of unpleasant and neutral images within the same block, and participants had to make emotional judgments about the images in one block and nonemotional judgments about the images in another block. Because making nonemotional compared to emotional decisions about IAPS pictures has been shown to reduce measures of emotional processing using both functional magnetic resonance imaging (Hariri, Mattay, Tessitore, Fera, & Weinberger, 2003; Keightley et al., 2003) and event-related potential (Hajcak, Moser, & Simons, 2006) techniques, combining these tasks may have reduced the likelihood of finding differences. It is also worth noting that participants in the Oliveri et al. study had to make motor responses to pictures, whereas participants in the present study did not.

Additionally, the present study recorded MEP amplitude from the APB muscle, whereas the Oliveri et al. (2003) study recorded MEP amplitude from the first dorsal interosseous muscle. Thus, another important issue that should be addressed in future research is the specificity of the present findings to the APB muscle. It will be important to determine whether similar results can be obtained from other muscle groups—and whether emotional facilitation of MEP amplitude will vary based on whether a muscle has a flexor or an extensor function, whether it is proximal or distal, whether the muscle is located in the hand or leg, and so forth.

It should be noted that the present data have been interpreted in terms of emotion facilitating action; an important future step will be to examine whether increased cortical excitability relates to behavioral indices of approach and withdrawal movements (Chen & Bargh, 1999; Duckworth, Bargh, Garcia, & Chaiken, 2002). Future studies might also extend this work using TMS to measure alternative measures of cortical excitability, such as the cortical silent period elicited by TMS during muscle contraction (Wassermann et al., 1993).

Although motor cortical excitability was modulated by emotional processing in the present study, the magnitude of this effect appeared unrelated to individual differences in how pictures were rated: Neither valence nor arousal ratings of pleasant and unpleasant pictures predicted the between-participant degree of modulation of cortical excitability. It is possible though, that some pictures elicited larger increases in MEP amplitude than others. This possibility could not be addressed in the present study because we did not record which pictures were presented during which pulses. Additionally, it is possible that the lack of an interindividual relationship between MEP facilitation and picture ratings is due to the fact that rMT is a baseline that is not standardized across participants; that is, the response magnitude for determining rMT is constant and does not take an individual's maximum MEP into consideration. Future studies could address these possibilities by employing within-participant comparisons between picture ratings and MEP amplitude.

In addition, individual differences in affective traits have been related to measures of cortical excitability (Oathes & Ray, 2006; Wassermann, Greenberg, Nguyen, & Murphy, 2001). Similarly, then, individual differences in emotional reactivity might relate to the degree of emotional modulation of motor cortical excitability. Examining the effect of emotional processing on MEP

amplitude with TMS could be an exciting method to utilize in studies of psychopathology. For instance, given the fact that hyperarousal is a core symptom of posttraumatic stress disorder (PTSD), it would be interesting to examine whether measures of cortical excitability, and the degree to which cortical excitability is modulated by emotional processing, are increased in patients with PTSD and whether these measures would be sensitive to treatment-related symptom changes.

In sum, TMS appears to be a useful tool for understanding the functional organization of emotional processing. The present data suggest that motivationally salient stimuli increase motor cortex excitability. Future research is needed to extend these findings by examining other measures of motor cortex excitability and inhibition, to examine the specificity of these results across multiple muscle groups, and to explore the within-subjects relationships between emotional ratings and MEP modulation. An important future step will be to examine whether cortical excitability during emotional processing can be used to better understand individual differences in emotional processing related to psychopathology.

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