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RESEARCH ARTICLE

Assessing the neural correlates of self-enhancement bias: a transcranial magnetic stimulation study

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Abstract Considerable research has focused on overly positive self-perceptions (self-enhancement), and yet little is known about the underlying neural mechanisms. The present study sought to assess the neural correlates of self-enhancement by applying Transcranial Magnetic Stimulation (TMS) to three brain regions. Twelve participants rated their best friend, as well as the self on a set of desirable or undesirable traits while TMS pulses were delivered in a virtual lesion manner. During the baseline condition (Sham TMS), participants produced more desirable and fewer undesirable ratings for themselves as compared to their best friend, showing self-enhancement. Compared to Sham TMS, TMS delivered to the Medial Prefrontal Cortex (MPFC) reduced self-enhancement whereas TMS delivered to the Supplementary Motor Area (SMA) and the precuneus did not. Together, these findings suggest that the MPFC may influence self-enhancement.

Keywords Medial prefrontal cortex · Transcranial magnetic stimulation · TMS · Self-enhancement · Self-deception · Self-perception

Introduction

Little is known about the neural mechanisms underlying overly positive self-evaluations (i.e., self-enhancement bias), despite the numerous studies that have been carried out on self-enhancement and its relation to mental health (e.g., Bonanno et al. 2002; Colvin et al. 1995; John and Robins 1994; Kwan et al. 2004; Paulhus 1998; Sedikides et al. 2004; Taylor et al. 2003). However, both functional neuroimaging studies and those examining patient populations have indicated a possible role for positive self-biasing in the Medial Prefrontal Cortex (MPFC).

While there have been no direct, specific measures of the neurological correlates of self-enhancement bias, there is growing evidence that the functional brain networks involved in processing self-related information involve the MPFC in the evaluation of the self. Significant MPFC involvement has been found during self-evaluation (Craik et al. 1999; Fossati et al. 2003; Johnson et al. 2002; Lou et al. 2004; Ochsner et al. 2005) and general self-reflection (Gusnard and Raichle 2001; Lieberman et al. 2004). For example, Ochsner et al. (2005) examined the neural correlates of directed ('how you perceive yourself') and reflected ('how you think others perceive you') self-evaluation. Directed self-evaluation resulted in significant activation in MPFC, right Prefrontal Cortex (PFC), and Anterior Cingulate Cortex (ACC) whereas reflected self-evaluation activated

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regions of the orbital frontal, insula, and temporal cortices. Taken together, these findings suggest that directed evaluations of the self-involve MPFC and its related structures. Ochsner et al. (2005) also included a review of the literature highlighting the role of MPFC (and the ACC) across a number of studies (see also Mitchell et al. 2004, 2005) and found that there was consistent activation of MPFC during tasks that involve self-evaluation.

Furthermore, false memories of the self appear to activate regions of the MPFC and the ACC (Okado and Stark 2003) as well as occipital areas (Slotnick and Schacter 2004). These regions also appears critical for self-identify (Girodo et al. 2002) and autobiographical responding, including overt falsification of autobiographical information (Nunez et al. 2005). The MPFC, but the ACC in particular, also appear to be involved in conflict monitoring (Yeung and Cohen 2006), including the integration of disparate information concerning the self. Botvinick et al. (2004) suggest that the ACC responds to conflict by triggering compensatory cognitive (and perhaps direct motor) mechanisms. Enhancement of the self may be one such compensatory mechanism such that the ACC and the MPFC are involved in moment-to-moment monitoring (and possibly adjusting) evaluations of self-worth. Moreover, MPFC is found to be critical to social interactions, including the comparison of self to others (for review, see Amodio and Frith 2006).

The MPFC has also been implicated in the deception of others. Using fMRI, Langleben et al. (2005) found increased superior medial and inferolateral prefrontal cortical activation during deception. Ganis et al. (2003) found similar MPFC activation, as well as ACC, motor, and occipital increases during deception. Lee et al. (2002) and Spence et al. (2001) found MPFC, ACC, and bilateral regions activated during deceptive responding as compared to truthful responding. Spence et al. (2005) recently concluded that MPFC and ACC are involved in producing deception.

Patient data also provides suggestive evidence that self-enhancement may be mediated via MPFC. Rankin and colleagues (Rankin et al. 2005) demonstrated that patients with Frontotemporal Dementia (FTD) exaggerated positive personality qualities while minimizing negative ones when compared to normal controls. There is a general deficit of accuracy in self-evaluation and error monitoring in FTD (e.g., O'Keeffe et al. 2007; Ruby et al. 2007) which may contribute to self-enhancement. It is therefore plausible that self-enhancement may be mediated in part via contributions of MPFC.

To test for such a possibility, we delivered Transcranial Magnetic Stimulation (TMS) to the MPFC using a 'virtual lesion' technique (Pascual-Leone et al. 1999). Employing TMS in this manner allows one to briefly disrupt processing in brain regions during a cognitive task at a temporal resolution of ~10–50 ms and a spatial resolution of 1 cm^2 (e.g., Fuggetta et al. 2006). An important advantage of this technique is its ability to determine the causal role of the neuroimaging findings in self-enhancement.

With this in mind, we delivered TMS to the MPFC to determine its role in self-enhancement. Self-enhancement is frequently defined as the discrepancy between how the individual perceives the self and the way the individual perceives others (e.g., Alicke 1985; Campbell et al. 2000): self-enhancers are those individuals who perceive themselves more positively than they perceive others. Thus, to measure self-enhancement, participants rated their best friend and themselves on a number of desirable and undesirable traits. On a behavioral level, we expected to replicate previous findings on self-enhancement, that is, participants would indicate more desirable and fewer undesirable ratings for themselves as compared to their best friend during the baseline condition (Sham TMS). Crucially, we predicted that TMS pulses delivered to the MPFC would affect self-enhancement. That is, if MPFC is involved in self-enhancement, disruption of these regions should result in a change in self-enhancement.

To control for the possibility that TMS disrupted self/other differences in general (as opposed to specific processes involved in self-enhancement), we also stimulated the precuneus (Pz). This region has been found to be more engaged when processing self-related information (compared to other) across a wide range of self-evaluative tasks from participants attributing food preference (Seger et al. 2004) to personality attributes (Lou et al. 2004). However, precuneus has not been implicated in either conflict monitoring or deception, and thus we did not expect it to be involved in self-enhancement. Therefore, we predicted that TMS delivered to the precuneus would disrupt general self/other differences (e.g., reaction times to make self-evaluations), but not significantly influence self-enhancement. Finally, the supplementary motor area (SMA) was also targeted as a control stimulation site, because it has not been implicated in either sellf/other differentiation or enhancement/deception.

Methods

Participants

Twelve university students (ten females and two males; age M 20.9 and SD 1.4) were recruited via flyer and word of mouth for the study. All participants were paid $25 for their participation and they were treated in accordance to the guidelines set forth by the Institutional Review Board at Montclair State University and the guidelines of the American Psychological Association.

Materials

A Magstim, single-pulse TMS device was used for all stimulation. A 70 mm, figure-of-eight coil was used throughout the experiment. All stimuli were presented on a Dell desktop with a 17″ CRT monitor. All triggering occurred through BioPac amplifiers, which were also used for motor threshold (MT) determination. All stimuli were adopted from Craik et al. (1999).

Procedure

The guidelines of Wassermann (1998) were used to set the limits of stimulation throughout the entire testing session. The testing involved two phases: MT determination and the main experiment. The participants were first fitted with a tight fitting lycra swim cap. Single suprathreshold TMS pulses were then delivered in an attempt to locate the region that provided the maximal MEP response in the contralateral Abductor Pollicis Brevis (APB) muscle. The coil was moved until the region was found that induced MEPs of maximal peak-to-peak amplitude. Determination of individual MT was employed using procedures as outlined by the IFCN (Rossini et al. 1994), such that threshold was established when 50% (five of ten) of the TMS pulses delivered induced a measured MEP of $\geq 50\ \mu V$. All stimulation was delivered at 90% MT. All MT measurements were made via BioPac MP150 amplifiers and software. Once the MT intensity was determined, the cap was marked in the 10/20 International system for EEG electrode positions.

The regions of interest were the Precuneus (Pz), the anterior portion of the MPFC, and the SMA. In terms of the possible direct ACC effects, the anterior MPFC corresponds with more rostral/anterior regions of the ACC (Hayward et al. 2004). Stimulation sites and measurements were similar to the anterior and posterior active sites described in Hayward et al. (2004). First, one-third of the distance, nasion to inion was measured for each participant. MPFC cortex was 1.5 cm anterior to this location and SMA was identified as being 3 cm posterior from this location (see also Harmer et al. 2001) (see Fig. 1). The coil was oriented parallel to the mid-sagittal line for all stimulation, with the handle pointed in a posterior orientation (except for APB MT determination in which the coil was held at ~45° from the hemispheric line).

To confirm that SMA was targeted, an independent group of participants were examined ($N = 3$) in which the methods of Obhi et al. (2002) were compared to those of Hayward et al. (2004). Briefly, MEPs were measured from the left tibialis anterior. TMS was delivered at 130% APB MT over region Cz and moved along the mid-sagittal line until maximal tibialis anterior MT was determined. From here, the coil was moved in an anterior direction until there were no recorded MEP responses. The coil was moved anterior from this point by 1 cm. The location of this region (identified as SMA; Obhi et al. (2002); S. S. Obhi, personal communication) was comparable (<1 cm difference) with the regions identified by Haward et al. (2004). To further ensure we were not targeting motor areas, we measured tibialis anterior MEPs during a shortened version of the task. No MEPs were found during stimulation at any of the sites. Finally, to ensure that 90% MT TMS was strong enough to disrupt task performance, we examined stroop performance using the same sites and stimulation parameters in a separate group of participants and found results comparable with those of Hayward et al. (2004).

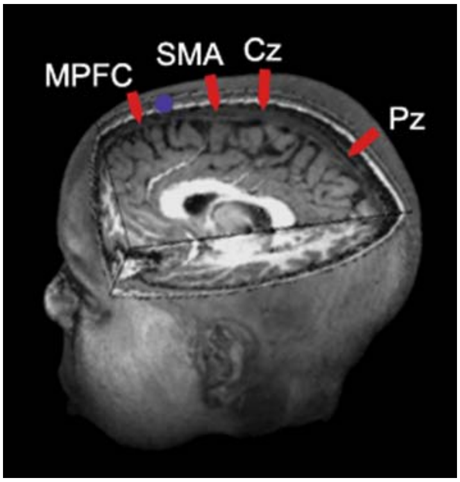

Fig. 1 Three-dimensional rendering of a participant's head to illustrate the relationship between the sites stimulated with TMS and the underlying cortex. The MRI was a full-volume structural dataset obtained using SPGR imaging on a Siemens scanner (128, 1.3 mm thick sagittal slices). The distance between the nasion and the inion (localized in the MRI by means of visual inspection), along the scalp, *d*(N,I), was measured on a sagittal slice passing through the center of the head. This distance was determined via approximation of the scalp outline with 50 short line segments and by summing their length. The location of Cz was computed by multiplying *d*(N,I) by 0.5 and by finding the corresponding point on the scalp in the sagittal slice. Similarly, Pz was located by finding the point on the scalp in the sagittal slice that had a distance of $d(\mathrm{N,I}) \times 0.3$ from the inion. To determine the SMA and MPFC sites, first the point on the scalp that had a distance of $d(\mathrm{N,I}) \times 0.333$ from the nasion was found. The site corresponding to SMA was 3 cm posterior to this point whereas the site corresponding to MPFC was 1.5 cm anterior to it (see text for details)

Baseline performance was measured by a Sham condition. During Sham, the TMS coil was held at a 90° orientation and held over Cz (standard 10/20 system coordinates). Because the regions (MPFC and SMA) are somewhat adjacent, single-pulse TMS was employed to avoid cortical spread. The coil was held manually (e.g., Lou et al. 2004) to ensure quick shifting of blocks, as they changed approximately once per minute. For all testing sessions, the participants wore protective earplugs to prevent transient threshold shifts caused by exposure to the acoustic artifact generated by the discharge of the TMS coil (Wassermann 1998).

Measures of self-enhancement

To measures self-enhancement, we selected 144 trait adjectives from Anderson's (1968) list. The 144 words were divided into eight blocks, each containing 18 adjectives. For each block, six adjectives were desirable [the highest rated from Anderson (1968)], six were neutral (those with ratings in the middle), and six were undesirable (those with the lowest ratings). For each brain site, two lists of adjectives were presented: one for self ('does this word describe you?') and for other ('does this word describe your best friend?'). Therefore, for each block (e.g., self-ratings at Pz) a total of 18 words were presented. All adjective presentations were randomized within the lists and all lists were counterbalanced across the participants. To minimize coil movement between the blocks, we applied TMS at each brain site for self and other before moving to the next brain region. The order of all brain region sites was randomized, as were the starting ratings within each block (self or other). All adjectives within a block were also randomly presented.

Participants indicated their response (yes or no) via a standard keyboard. Response times (RTs) were measured as the time of adjective onset to key response. TMS was delivered 500 ms after adjective onset for all trials (see Fig. 2).

To compute an index of self-enhancement, we first assigned a value of '1' to a 'yes' response and a value of '0' to a 'no' response to the desirable adjectives. We then did the reverse (−1 for a 'yes' response) for the undesirable adjectives and added the partial scores so that a total value over 0 indicated a tendency to respond positively, whereas a value under 0 indicated a tendency to respond negatively. Second, we compared the ratings for self to the ratings for the best friend. For example, a person may have had a self-rating of 3 (indicating 3 more desirable attributions than undesirable attributions) and a friend rating of 1 (indicating only 1 more desirable than undesirable attribution to the best friend). This person's self-enhancement rating would therefore be 2.

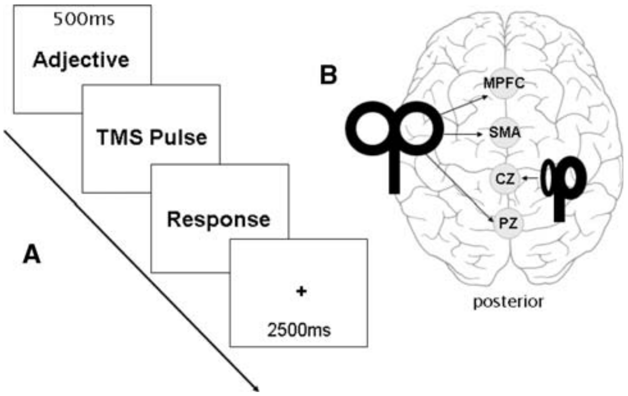

Fig. 2 Experimental design. Participants were asked to rate themselves and their best-friend using adjectives that were either positive, neutral or negative. During the task, TMS was delivered 500 ms after adjective presentation with a 2,500 ms ISI. (**a**) During the two conditions, participants rated if the adjectives described themselves or their best friend with a 'yes' or 'no' response. (**b**) TMS was delivered to the MPFC, SMA, Pz with a mid-sagittal orientation and to Cz (sham) with a 90° coil orientation

Experimental design and data analysis

There were three main independent variables: Brain Site (Sham, MPFC, SMA, and Pz); Target Person (Self and Other); Trait (Desirable, Neutral, and Undesirable). The main dependent variables were self-enhancement scores and RTs (ms). All data were analyzed in SPSS Version 12.0.

Results

Self-enhancement scores were compared as a function of brain region using a one-way repeated measures ANOVA. There was a significant effect of brain site [$F(3,33) = 5.50$ and $P < 0.004$]. To test for specific effects, we first compared the active conditions to sham using alpha-corrected deviation contrasts. The contrast between sham ($M = 0.42$ and $SE = 0.24$) and the MPFC stimulation site [$M = -0.04$ and $SE = 0.29$; $F(1,11) = 4.57$ and $P = 0.05$] showed a significant effect, indicating that MPFC stimulation reduced self-enhancement. There was no significant reduction for the Pz stimulation [$M = 0$ and $SE = 0.42$; $F(1,11) = 2.52$ and $P = 0.14$]. These findings support the hypothesis that MPFC stimulation specifically reduces self-enhancement. The control conditions (sham and SMA) were compared, and a significant difference was found [$F(1,11) = 7.61$ and $P = 0.019$] such that there was greater self-enhancement at the SMA site ($M = 1.17$ and $SE = 0.20$). When compared to SMA, there was reduced self-enhancement for both MPFC ($P = 0.0002$) and Pz ($P = 0.004$). There was no difference between MPFC and Pz ($P > 0.05$) (Fig. 3).

Because it was possible that the changes in ratings might have been due only to self-ratings becoming more positive (or ratings of others becoming more negative), we examined the role of each separately. We combined the positive (+1 for each) and negative (−1 for each) ratings self-only and compared these ratings across brain regions. There were no significant differences across brain site for self-ratings [$F(3,33) = 1.71$ and $P = 0.184$]. Likewise, there was no difference for the ratings of others [$F(3,33) = 0.46$

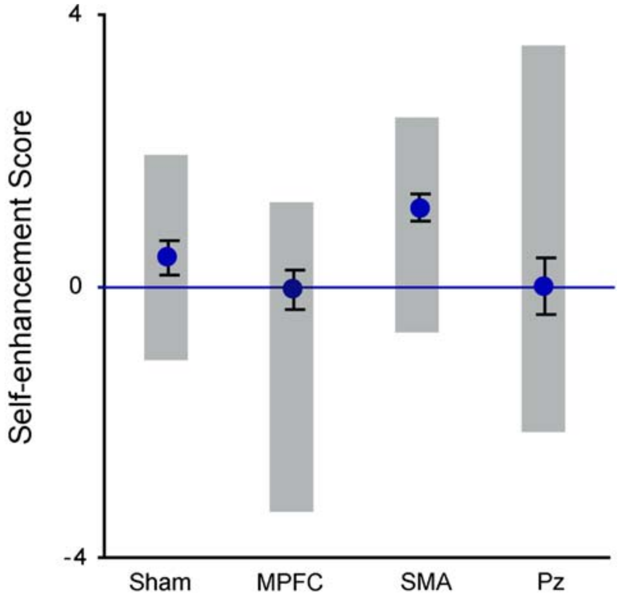

Fig. 3 Self-enhancement was significantly reduced when TMS was delivered to MPFC ($P < 0.05$) when compared to sham. When compared to SMA, TMS delivered to both MPFC and precuneus were significantly reduced. Means, standard errors and ranges (*gray bars*) of self-enhancement scores are displayed. Note that the standard error bars and ranges shown here indicate the between-subject variability

and $P = 0.714$]. These data demonstrate that the self-enhancement was not exclusively due to changes in ratings of self or other.

The overall RT was 793.22 ms ($SE = 59.56$). To determine if there were RT differences across any of the conditions, we conducted a 4 × 2 × 3 (Brain Site × Target Person × Trait) Repeated Measures ANOVA. The overall three-way interaction was not significant, $F(6, 66) = 1.28$ and $P = 0.278$. All two-way interactions were also not significant with the exception of the Target Person × Trait interaction, $F(2, 22) = 3.85$ and $P = 0.037$.

The one planned comparison with RT was to examine the effect of self and other differences using neutral adjectives. Prior to the experiment, we suspected that power may have been an issue in the overall interaction being non-significant so we minimized the variables in a specific comparisons. This comparison was important, as neutral adjectives provide the ability to distinguish self and other differences without the influence of self-enhancement. Using a series of alpha adjusted *t*-tests, ratings of the self and other were compared for the neutral adjectives only. In the Sham condition, there was a significant difference in ratings between the self and other ($P = 0.004$), such that RT was quicker for self ($M = 818.60$) than for other ($M = 970.51$). However, TMS delivered to all other regions resulted in a non-significant difference between ratings of the self and ratings of other (all $P > 0.05$), suggesting that mid-line stimulation disrupted self and other judgments. These findings provide evidence that self and other distinctions center, at least in part, on the mid-line regions. That is, the disruption of MPFC, SMA, or Pz results in a reduction of the self-effect (i.e., the RT advantage for rating the self). However, as the overall three-way interaction was non-significant, we suggest that these data be interpreted cautiously.

Discussion

Our findings show that TMS delivery to MPFC decreased participants' tendency to self-enhance when compared to Sham and SMA TMS. TMS delivery to the precuneus only disrupted self-enhancement in comparison to SMA TMS. Together, these findings suggest that the MPFC might influence self-enhancement. Previous research showed that MPFC is activated during deception of others (Ganis et al. 2003; Langleben et al. 2005; Spence et al. 2001) and self-deception (Okado and Stark 2003; Slotnick and Schacter 2004). Our findings provide further evidence that self-deception (positive self-illusions), as indicated by self-enhancement may be mediated via the MPFC. The data are suggestive of a lesser, supporting role for precuneus.

By employing TMS in a virtual lesion manner, causal links between brain region and behavior can be established. In the current study, the link between MPFC and self-enhancement appears important, though future studies are needed to establish a definitive causal link. It remains unclear whether this link is specific to self-enhancement, self-deception, or deception in general. Future studies should address this possibility. Because there was suggestive evidence that self and other differences were minimized in terms of RT for the neutral adjectives, the present findings provide initial evidence that the MPFC effect may be unique to self-enhancement rather than self and other differences. That is, while all the regions stimulated (MPFC, SMA, and Pz) appear important for differentiating the self from other (Lou et al. 2004), only MPFC appears to be highly involved in self-enhancement.

Because MPFC has projections to orbital-frontal regions, it is possible that self-enhancement involves a MPFC-orbitofrontal circuit (and/or possibleACC-orbitofrontal circuit). Given its anatomical connections, the orbitofrontal cortex is in a position to integrate sensory and visceral motor information to modulate behavior through both visceral and motor systems (Price 1999). This has led to the proposal that the orbitofrontal cortex is an important part of the networks that are involved in emotional processing (e.g., Price 1999; Schoenbaum 2004). If orbitofrontal cortex involves in self-enhancement, the self-enhancement effect we observed may be in part due to changes in affect. While no mood ratings were obtained in the present study, we did not notice any observable changes in the participants' mood following stimulation. Nevertheless, it would be interesting for future research to examine the link between self-enhancement and affect.

Another interesting direction for future studies is to examine the role of timing in further elucidating the role of the MPFC in self-deception. It is possible that different regions of the MPFC are involved in self-enhancement at different times. Such studies could map out the 'where and when' of the process of self-enhancement, such has been used for other cognitive and perceptual abilities (see Beckers and Zeki 1995). The timing of the stimulation used here was based on pilot data in which we found a modest effect, but different temporal parameters are likely to have an influence (Nessler et al. 2004). This may in fact elucidate the role of precuneus in self-enhancement. We found only significance between the precuneus and SMA, and it is possible that earlier timings (e.g., Lou et al. 2004) might disrupt self-enhancement at precuneus.

Direct stimulation of the orbital-frontal cortex might also reveal valuable information; however because this region is difficult to reach via TMS, concurrent monitoring with fMRI might be necessary (e.g., Li et al. 2004). Further studies could also employ repetitive TMS (rTMS). Based on the present findings, we predict that high-frequency rTMS (e.g., 20 Hz) delivered to MPFC (immediately preceding the task) would increase self-enhancement because it increases neural activity in regions proximal to the TMS. In contrast, low-frequency (e.g., 1 Hz) rTMS would reduce self-enhancement as it appears to increase inhibitory activity in proximal regions. Also, other populations should be tested. First, the majority of our participants were female (83.3%). It is possible that this played a role in self-enhancement in general and perhaps the neural underpinnings. We also acknowledge the tenuous nature of SMA stimulation in this study. Our exploratory method, while likely sound, should also be replicated in future studies.

Finally, it should be noted that delivery of TMS to MPFC may or may not disrupt ACC. It has been found that MPFC stimulation disrupts stroop performance (Hayward et al. 2004), a task associated with ACC (see Kerns et al. 2004). Imaging studies also suggest that TMS delivered to fontal regions changes activity in the ACC (Barrett et al. 2004; Bestmann et al. 2005; Ohnishi et al. 2004; Siebner et al. 2001). However, it has been found that stimulation strength (and thus direct effects of TMS) deteriorates significantly and that at penetration depths beyond 2 cm, intensity significantly dissipates (Thielscher and Kammer 2004). The changes noted in ACC following TMS may in fact be indirect changes (via cortico-ACC transmission).

As we delivered TMS at 90% of MT, it is unlikely that ACC was stimulated directly, though it is possible that ACC was disrupted via cortico-ACC connections. While it is almost certain that TMS delivered to frontal portions of the skull disrupts activation in MPFC (see Theilscher and Kammer 2002 for mapping of cortical surface targeting), the direct effects on ACC resulting from scalp TMS are not yet conclusively known. Therefore, a more focused program of research is needed to pinpoint the role of ACC in self-enhancement.

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