Comparison of brain activation during norm-referenced versus criterion-referenced feedback: The role of perceived competence and performance-approach goals

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ABSTRACT

The patterns of brain activation during norm-referenced and criterion-referenced feedback were compared, using the functional magnetic resonance imaging (fMRI). Twenty-two healthy right-handed individuals performed a series of perceptual judgment tasks while their brain activity was recorded. The participants responded to a performance-approach goal survey and performed practice trials prior to scanning, during which their perceived competence toward the novel task was manipulated with bogus performance information. During scanning, the participants received either norm-referenced or criterion-referenced feedback after each performance. The brain regions associated with negative affect including the posterior cingulate cortex, the medial frontal gyrus, and the inferior parietal lobule were recruited during norm-referenced feedback only among the low-competence participants. In contrast, significant activation was observed in the identical cortical areas involved in negative affect during criterion-referenced feedback only among the high-competence participants. Regardless of the level of perceived competence, performance-approach goal scores correlated positively with activation in the brain areas implicated in the negative emotion during norm-referenced feedback. The present findings provide insight into the potential costs and benefits of normative assessment.

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1. Introduction

Criterion-referenced and norm-referenced assessments represent two main types of assessment used for delivering an overall evaluative judgment about the quality of student performance. These two types of assessments are distinguished primarily by the standards against which student’s performance is compared (Linn & Gronlund, 2005). Criterion-referenced assessment, which is frequently used by teachers to foster individual learning (Pelleg-rino, Chudowsky, & Glaser, 2001), compares each student’s performance to some pre-established criteria, often in the form of specific learning objectives. Students’ scores are determined by the degree of their mastery on these objectives, regardless of how other students performed on the same objective. In contrast, norm-referenced assessment, which is a more prevalent form of evaluation in the large-scale standardized assessment for high-stakes test (Rakoczy, Klieme, Bürgermeister, & Harks, 2008), compares each student’s performance to the performance of others in the same reference group. Students’ scores are largely determined by the relative superiority or inferiority of their performance compared to those of other students, regardless of how much of the specific learning objectives they successfully mastered.

Each assessment serves a distinctive purpose and reflects a separate conceptual dimension of tests (Carver, 1974). Criterion-referenced assessment focuses on measuring within-individual gain or growth (edumetric dimension) which is important for instructional decision-making, whereas norm-referenced assessment focuses on measuring between-individual differences (psychometric dimension) which is important for placement or policy decision-making. Criterion-referenced assessment is more appropriate for a classroom test whose purpose is to foster individual learning and development rather than ranking and selection, because it provides students with clear performance standards and controllability over their own learning (Neil, Wadley, & Phinn, 1999). Many educators have warned about the potential danger of norm-referenced assessment and strongly advocated the use of criterion-referenced assessment. They point out the particularly debilitating effects of normative feedback on students’ continued motivation, which often result in heightened anxiety and lowered perceived competence (Covington & Omelich, 1979; McClelland, 1973; Nicholls, 1979; Slavin, 1980).

Despite such warning, norm-referenced assessment continues to enjoy what appears to be increasingly wider application in the classroom. In recent times, the widespread use of high-stakes stan-
dardized achievement tests have led to the increasing dominance of norm-referenced assessment in classroom (Black & William, 1998; Shepard, 2000). This tendency is particularly salient in East Asian countries with highly competitive education systems, where social comparison is a quite prevalent phenomenon (Shih & Alexander, 2000; White & Lehman, 2005). On the contrary, there is a growing trend of introducing criterion-referenced assessment in higher education (Carlson, MacDonald, Gorely, Hanrahan, & Burgess-Limerick, 2000; O’Donovan, Price, & Rust, 2000).

Although the controversy over norm-referenced versus criterion-referenced assessment continues (Lederman & Burnstein, 2006), few studies to date have systematically compared the effects of criterion-referenced and norm-referenced assessments on cognition and affect. The primary purpose of the present research was, therefore, to investigate developmental cognitive and affective responses to each type of assessment by measuring brain activation patterns using the functional magnetic resonance imaging (a.k.a., fMRI). Based upon the brain areas activated and evidence from previous findings in the field of cognitive, affective, and social neuroscience, we sought to make plausible inferences about the participants’ cognitive and affective responses to these types of assessment. The secondary purpose was to examine whether these effects were moderated by individual characteristics such as perceived competence and performance-approach goals.

2. Looking at the same problem with a different lens

Although it may be possible to address the above-mentioned research questions via surveys or field experiments, these designs only allow examination of consequent processes in an a posteriori manner. The sole reliance on learners’ retrospective memory raises a problem of accuracy. In addition, because people have only restricted conscious access to their implicit emotional and cognitive processing (e.g., Panksepp, 2005), the survey method does not allow drawing reliable inferences about the participants’ psychological processes during feedback processing. In the context of the present study, self-report surveys and behavioral observations cannot capture the exact cognitive and affective reactions occurring in learners’ minds either during or immediately after they receive one or the other type of feedback on their performance. What makes matters more complicated is the finding that cognitive and affective responses resulting from social comparisons, including norm-referenced feedback, are basically spontaneous, effortless, and unintentional reactions (Gilbert, Giesler, & Morris, 1995; Tessier, Millar, & Moore, 1988). How, then, can one understand implicit cognitive and affective responses during feedback processing?

Neuroimaging techniques could provide an answer to this dilemma. With the recent advent of cognitive and affective neuroscience, it has become possible to document cognitive mechanisms that are both automatic and fast as well as affective mechanisms that are implicit and fine-tuned. Neuroimaging techniques were deemed especially better suited for the present research purposes because they permit identification of the in vivo neural substrates of implicit cognitive and affective processes during the reception of feedback.

Among many such techniques, the fMRI was used in this study. Functional MRI study measures blood oxygen level-dependent (BOLD) signals, which are closely coupled to regional cerebral blood flow (CBF) associated with neuronal activity (Huettel, Song, & McCarthy, 2004). Because the BOLD response tends to be stable across trials within each experimental condition, most fMRI studies use within-subject designs in which the same participant is exposed to two or more conditions. Then, the brain activation patterns of the same individual between conditions are compared. If certain brain areas demonstrate relatively stronger activation during one condition than the other, researchers can identify functions associated with those areas and make reasonable inferences regarding the underlying psychological processes. To facilitate a direct comparison between norm-referenced and criterion-referenced feedback conditions, no other control condition was used in this study.

The fMRI technique encapsulates the patterns of brain activation during the very moments they are receiving the very feedback. The brain activation so captured is believed to be relatively free of social desirability, false or selective recollection, and insincere or otherwise unreliable responses. Therefore, it is possible to generate credible inferences regarding the ongoing cognitive and affective processes elicited by each type of feedback.

3. Mixed claims with mixed evidence

Previous research in the field of motivation has demonstrated that providing norm-referenced feedback to learners tends to undermine their intrinsic motivation by lowering their interest in the task and preventing them from enjoying the activity for its own sake (e.g., Butler, 1987). Furthermore, lack of direct control over the results of evaluation in norm-referenced assessment permits students to more easily rationalize their poor performance and decrease their effort (Williams, Pollack, & Ferguson, 1975). In Asian countries with highly competitive education systems, where standardized achievement tests have led to the increasing dominance of norm-referenced assessment in classroom (Black & Wiliam, 1998; Shepard, 2000), the survey method does not allow drawing reliable inferences about the participants’ psychological processes during feedback processing.

The brain activation so captured is believed to be relatively free of social desirability, false or selective recollection, and insincere or otherwise unreliable responses. Therefore, it is possible to generate credible inferences regarding the ongoing cognitive and affective processes elicited by each type of feedback.

4. The moderating role of perceived competence and performance goals

These seemingly contradictory findings on the consequences of norm-referenced feedback may be resolved when considering perceived competence as a potential moderator. The social comparison literature suggests that downward comparisons (to those doing worse than the self) are more likely to boost competence, engender positive affect and reduce anxiety, whereas upward comparisons (to those doing better than the self), although yielding more useful information for self-evaluation, tend to lower competence and generate negative affect (Buunk, Collins, Taylor, Van Yperen, & Dakof, 1990; Wills, 1981). Therefore, norm-referenced feedback may serve the goal of self-enhancement, self-assessment, or self-improvement better for individuals with high perceived
competence, provided that their competence is validated and maintained as a result of the social comparison (Taylor, Neter, & Waymert, 1995). In contrast, those with low perceived competence could suffer from feelings of vulnerability and negative affect upon receiving norm-referenced feedback, unless they outperformed many others.

There is supporting evidence that low-achieving students indeed showed less motivation when their performance was pitted against those of others, compared to when it was evaluated against some objective standard (Kramen, 1987). Conversely, in the study of Williams et al. (1975), high-achieving college students in the norm-referenced grading system tended to score higher on tests than did those in the criterion-referenced grading system. Narciss (2004) also found that self-efficacy was a critical moderator for the differential benefits of feedback. That is, providing normative feedback was more beneficial in terms of achievement, persistence, and satisfaction for students with high self-efficacy than it was for students with low self-efficacy.

Another important individual characteristic that is likely to moderate the effects of different types of feedback might be a performance-approach goal. A performance-approach goal is one of several achievement goals students could adopt in achievement situations. An achievement goal refers to underlying reasons and purposes for engaging in achievement-related behaviors in particular settings (Ames, 1992; Dweck & Leggett, 1988; Nicholls, 1984). Students who endorse mastery goals strive to develop their competencies by engaging in academic activities. In contrast, the key concern for those who pursue performance goals is how their competence is evaluated against that of their peers. The desire to validate one's competence by demonstrating relative superiority is called a performance-approach goal, whereas that by concealing comparative iniquity is called a performance-avoidance goal (Elliot & Harackiewicz, 1996; Middleton & Midgley, 1997).

Because one of the critical features of a performance-approach goal is the focus on a normative standard of competence (Elliot & McGregor, 2001; Nicholls, 1984), students who strongly pursue performance-approach goals are expected to display differential cognitive and affective reactions to social comparative information compared with those who do not. An interesting research question is whether a performance-approach goal would produce positive or negative consequences when norm-referenced feedback is provided. This question is particularly interesting because the debate over the adaptive nature of a performance-approach goal has not yet been settled (e.g., Harackiewicz, Barron, Pintrich, Elliot, & Thrash, 2002; Midgley, Kaplan, & Middleton, 2001).

5. Neural basis of feedback processing

Most functional neuroimaging studies on feedback processing have focused on the differences in neural activity associated with feedback valence such as positive and negative feedback, rather than types of feedback. It has been well established that positive (correct) feedback induces positive emotions and reinforces the target behavior, whereas negative (incorrect) feedback produces error signal, engenders negative affect, and shapes appropriate behavior (e.g., Bischoff-Grethe, Hazeltine, Bergren, Ivry, & Grafton, 2009). Previous studies have shown that brain regions commonly associated with positive feedback are overlapping with the reward-sensitive areas such as the striatum and the medial orbitofrontal cortex (OFC) (Knutson, Adams, Fong, & Hommer, 2001; O’Doherty, Kringelbach, Rolls, Hornak, & Andrews, 2001), whereas negative feedback resulted in activation of the punishment-related area such as the lateral part of OFC (Gottfried & Dolan, 2004; O’Doherty et al., 2001) and of the brain regions associated with negative affect such as the medial frontal cortex, the inferior parietal cortex (Jimura, Konishi, & Miyashita, 2004; Zanolie, Van Leijenhorst, Rombouts, & Crone, 2008), and the posterior cingulate cortex (Van Leijenhorst, Crone, & Bunge, 2006; Wrase et al., 2007). In addition, the negative feedback processing also recruits the cognitive control network, a set of interconnected cortical regions responsible for executive processing to avoid further errors, including the anterior cingulate cortex (ACC) and the anterior insula (Liu et al., 2007; Ullsperger & von Cramon, 2001; van den Bos, McClure, Harris, Fiske, & Cohen, 2007).

However, there is no functional neuroimaging study to date to directly compare norm-referenced and criterion-referenced feedback. Only one recent neuroimaging study demonstrated that social comparison activated the reward-related brain area such as the ventral striatum, indicating that outperforming someone else is a rewarding experience (Fliessbach et al., 2007). Because no previous study has attempted to explicate the neural responses during norm-referenced and criterion-referenced feedback, it is difficult to make a priori prediction of the recruitment of specific brain regions associated with each type of feedback. Thus, this study was conducted to explore the neural underpinnings of both norm-referenced and criterion-referenced feedbacks and provide the most plausible explanation for the results on the basis of a growing body of evidence on the neural circuitry involved in cognitive and affective function.

6. Present study

The main objectives of this study were to identify distinctive brain regions that show relatively greater BOLD signal change in response to each type of feedback condition. The present research is the first to our knowledge that provides direct empirical evidence on the effects of criterion-referenced versus norm-referenced feedback on brain activation. We hypothesized that participants with low perceived competence would be more likely to lower their performance expectations and thus show more activation in the brain regions associated with negative affect upon receiving norm-referenced than criterion-referenced feedback. Alternatively, participants with high perceived competence would be expected to experience stronger negative affect during criterion-referenced than norm-referenced feedback due to their presumed preference of more diagnostic information regarding how well others are doing, which they could use to evaluate and confirm their own ability more accurately (e.g., Narciss, 2004).

There has been little empirical effort to directly assess the relationship between students’ performance-approach goals and their affective reactions in normative evaluation settings. However, available evidence suggests stronger negative reactions to normative feedback by individuals with strong performance-approach goals. In Bong and Kim (2006), for example, students with high performance-approach goals responded more negatively to the competition and emphasis on social comparison in their schools than did those with low performance-approach goals. As the students with high performance-approach goals perceived a stronger normative focus in their learning environment, they reported significantly less positive school affect, weaker feelings of school belonging, and lower interest in school learning. These negative relationships between perceptions of normative focus and school-related cognition and affect did not emerge among the students with low performance-approach goals. Accordingly, a significant positive relationship was hypothesized between participants’ performance-approach goals and negative affect during normative feedback processing.

In sum, our goal in the present investigation was to identify the functional neuroanatomy associated with each type of feedback and varying brain regions as a function of participants' perceived
competence and performance-approach goals. Findings from this study were expected to provide insights into the cognitive and affective responses to each type of feedback as well as potential costs and benefits of each type of assessment.

7. Method

7.1. Participants

Twenty-two healthy right-handed undergraduate students (12 men and 10 women; mean age = 22.4 ± 2.3 years) from diverse majors were recruited via online posting in Korea university in Seoul. The reason why we recruited right-handed participants was to control the variability in cerebral dominance and asymmetry which is related to handedness. They were given monetary rewards (approximately $30) for their participation in the experiment. Each participant provided an informed consent form according to the policies and regulations of the Institutional Review Board at Korea University. All participants were screened before the experiment for medications and any psychological or neurological conditions that might influence the measurement of cerebral blood flow.

7.2. Experimental tasks and procedures

7.2.1. Experimental tasks

The participants saw a computer screen filled up with 40–50 alphabet letters for 1 s each. Their task was to judge whether each of the letter sets presented on the screen contained more than three target stimuli (i.e., a designated alphabet letter; e.g., “T”). Participants were instructed to respond as fast and accurately as possible. We used these perceptual judgment tasks, which were deemed sufficiently novel to most college students, to control for potential pre-existing differences in the level of prior knowledge and perceived competence among the participants. Use of novel tasks also ensured that manipulation of perceived competence during practice trials would be successful and the bogus performance feedback presented after each experimental task would appear more credible to participants.

After perceptual stimuli disappeared from the screen, the participants were given 1.5 s to respond by clicking either a left (i.e., if they believed there were three or less target stimuli included in the letter set) or a right button (i.e., if they believed the letter set contained more than three target stimuli) on the mouse. A fixation period of 1.5 s then followed, after which performance feedback was presented for another 1.5 s. The experimental tasks were programmed and presented using E-PRIME v. 1.1. All stimuli were visually shown via a LCD monitor installed in front of the scanner camera. The basic experimental procedures for a single trial were depicted in Fig. 1.

7.2.2. Perceived competence manipulation

Perceived competence of the participants toward the experimental tasks was manipulated by providing bogus feedback during 40 practice trials prior to the scanning. They were given the same experimental task as would be given during scanning. Participants were randomly assigned to either a high- or low-competence condition. The participants received feedback that was pre-determined depending on their experimental conditions, regardless of their actual performance. Half of the participants received positive feedback (i.e., high-competence condition; “Your performance was [85–95]% correct and ranked in the top [5–15]%.”), whereas the other half received negative feedback (i.e., low-competence condition; “Your performance was [25–35]% correct and ranked in the top [65–75]%.”). To prevent any carry-over effects from this competence manipulation to the actual experimental sessions, we deliberately provided both criterion-referenced and norm-referenced feedback blocks during the practice trials.\(^1\) The participants were led to believe that the norm-referenced feedback (i.e., ranking) was determined by comparing their task performance to the norm established in a large database system.

7.2.3. Criterion-referenced versus norm-referenced feedback

The main experimental phase consisted of three sessions, each session containing 10 feedback condition blocks. Each of the 10 blocks in turn consisted of four trials of 30 s duration. Among the 10 blocks within each session, five blocks were of norm-referenced feedback and the other five were of criterion-referenced feedback. The criterion-referenced and norm-referenced feedback blocks were randomly interspersed. All participants were exposed to the

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\(^1\) The range of performance feedback was determined strictly through experimental testing. Because we have manipulated this type of bogus feedback in previous studies, we know the optimal ranges of feedback (percentile ranks or accuracy scores) to affect the level of competence for the novel task. For example, Kim, So, Yoon, Kim, and Lee (2004) manipulated the score of 91–95 and the rank of top 7–8% for high competence condition and the score of 65–69 and the rank of bottom 30% for low-competence condition. They found the significant differences in the level of competence by using very similar range of feedback \((r = 0.27, p < .01)\), indicating that this type of competence manipulation resulted in significant differences in the level of competence among college students. Another reason why we had not checked the manipulation in this experiment is that we thought asking participants to report their own competence level before scanning might influence their later performance differentially depending on the level of competence. Particularly in the case of low-competence group, once they admitted their lack of competence, they might be more likely to be sensitive and consider the upcoming feedback to be more unreliable to protect self-worth.
same number of criterion-referenced and norm-referenced feedback.

In the criterion-referenced feedback condition, performance feedback was presented as an accuracy score (i.e., [75–90]% correct for the high-competence group versus [15–30]% correct for the low-competence group). In the norm-referenced feedback condition, performance information was presented as a percentile rank (i.e., top [10–25]% for the high-competence group versus top [70–85]% ranking for the low-competence group). The specific numbers used for the accuracy and ranking indexes were adjusted closer to the middle and fluctuated within slightly wider bands compared to those used for the earlier competence manipulation, for the purpose of enhancing their credibility.

7.3.3. Statistical analyses

Analyses and correlation analyses. The subtraction analyses were subjected to voxel-wise statistical analyses. The preprocessed images of each participant (first-level individual analysis). Then these within-subject contrast images obtained per participant were entered as the data for the second-level group analyses. Group analyses were performed by using a random-effects model to generalize to the population from which data were acquired.

Correlation analyses were also performed to identify brain regions whose activation during norm-referenced feedback co-varied across participants’ performance-approach goals. We again used the contrast images where brain activation patterns during the norm-referenced feedback were compared to those obtained during the criterion-referenced feedback. These contrast images were regressed to the participants’ performance-approach goal scores.

In the present study, we used a conventional whole-brain threshold level of $p < .005$ uncorrected and defined the significant activation of the brain region as 10 or more significant contiguous voxels in the MNI coordinates. All coordinates were transformed from the MNI template to Talairach coordinates using Brett’s mni2tal. The anatomical locations of significant activation foci were identified using the Duvernay atlas (1991) and the Talairach and Tournoux standard stereotaxic space (1988).

8. Results

It was not possible to make a direct comparison between the competence groups because each group received completely different feedbacks which were not comparable at all. That is, both accuracy scores and percentile ranks presented as feedbacks for high-competence group were much higher than those for low-competence group. Thus, we performed all analyses separately for each competence group to control confounding effect of the levels of the feedback.

8.1. Subtraction analyses

To determine which brain areas were relatively more activated during each feedback condition, two separate subtraction analyses were conducted for the high and low perceived competence groups. Table 1 and Fig. 2 present the summary of brain areas associated with memory and attention respectively, and the parahippocampal gyrus and the superior parietal lobule which were associated with memory and attention respectively, and the precentral gyrus in the right hemisphere (see Table 1 and Fig. 2A).

Regarding the criterion-referenced feedback condition, the reverse $t$-test (i.e., criterion-referenced vs. norm-referenced) showed a significant activation in brain regions associated with
negative affect, including the right orbitofrontal cortex (OFC), the right posterior cingulate cortex, the right inferior parietal lobule, the left medial prefrontal gyrus, and the left anterior cingulate gyrus. In addition, the left superior parietal lobule, the left superior temporal gyrus, and the bilateral middle frontal gyrus were activated (see Table 1 and Fig. 2B).

For the low-competence participants, the brain regions activated during the norm-referenced feedback were the bilateral posterior cingulate gyrus, the left inferior parietal lobule, and the right medial frontal gyrus, which are the same areas activated by criterion-referenced feedback for the high-competence participants (see Fig. 3A). In contrast, the left superior parietal lobule, the right middle occipital gyrus, and the left postcentral gyrus were recruited during the criterion-referenced feedback (see Fig. 3B).

In sum, the criterion-referenced feedback activated the brain regions associated with negative affect for the high-competence participants, whereas the norm-referenced feedback activated the same brain regions for the low-competence participants.

8.2. Correlation analyses

Two separate correlation analyses were conducted for each competence group to examine how individual differences in performance-appraisal goals were associated with differences in neural processing of the norm-referenced feedback in comparison with criterion-referenced feedback. For the high-competence participants, activities in the brain areas responsible for negative emotional processing, including the insula, the putamen, the thalamus in the right hemisphere, and the left posterior cingulate cortex were positively correlated with the performance-appraisal goal scores during the norm-referenced feedback. Table 3 summarizes the brain areas activated for the high-competence group revealed by the correlation analyses. Fig. 4 displays the relationships between the performance-appraisal goal scores and the BOLD signal intensity in specific brain regions during the norm-referenced feedback processing.

When the norm-referenced feedback was compared with the criterion-referenced feedback conditions for the low-competence participants, positive correlations with performance-appraisal goal scores were observed in the left amygdala, known to process strong negative emotion, and the right temporal medial gyrus (see Table 4). Fig. 5 illustrates the association between the performance-appraisal goal scores and the BOLD signal intensity in the amygdala.

In sum, while receiving the norm-referenced feedback, participants with high performance-appraisal goals, regardless of their level of perceived competence, showed greater recruitment of brain areas implicated in the processing of negative affect.

9. Discussion

We compared brain activation during norm-referenced feedback with criterion-referenced feedback using fMRI in this study. The distinct pattern of brain activation associated with each type of feedback suggests that individuals do engage in discrete cognitive and affective responses while processing criterion-referenced or norm-referenced performance information. Furthermore, the present results provided strong support for the hypothesized role of perceived competence and performance-appraisal goals as potential moderators of feedback effects.

9.1. Role of perceived competence in feedback processing

The brain activation observed in the present study suggests interactive patterns between the types of performance feedback and the levels of individuals’ perceived competence toward given tasks. Different regions of the brain were activated depending on not only the types of feedback but also the levels of perceived competence while receiving the same feedback information.

It can be inferred that negative affect might be generated among the participants with low perceived competence during the norm-referenced feedback, as indicated by the significant activation of the posterior cingulate cortex, the medial frontal gyrus, and the inferior parietal lobule (see Fig. 3A). These regions represent brain areas consistently activated by aversive or unpleasant stimuli, including negative feedback (Jimura et al., 2004; Zanolie et al., 2008). In particular, the increased activity in the posterior cingulate cortex has been observed during negative feedback (Van Leijenhorst et al., 2006; Wrase et al., 2007), pain-related fear and anxiety (Ochsner et al., 2006), or emotional disorder such as depression (Joe et al., 2006; Maddock, 1999). This finding suggests that individuals with low competence perceive norm-referenced...
feedback as more aversive and unpleasant, compared with criterion-referenced feedback. However, the activation in these brain regions associated with negative affect was not found among the participants with high perceived competence during the norm-referenced feedback. Instead, the recruitment of the precuneus, which is known to be involved in self-processing tasks (Cavanna & Trimble, 2006; Northoff et al., 2006), was found. Self-processing means the processing of self-relevant information, which reflects high levels of self-awareness or self-consciousness. Thus, the activation of precuneus during norm-referenced feedback indicated that norm-referenced feedback appears to induce ego- rather than task-involvement among individuals with high perceptions of competence.

This interpretation is consistent with previous behavioral findings that feedback increases self-focused attention when it is not consistent with one’s expectations or beliefs (Kluger & DeNisi, 1996; Swann, 1987). The self-focusing effects of inconsistent feedback are found to be much more pronounced among high achievers receiving failure feedback (Brunot, Huguet, & Monteil, 2000). Because the performance feedback was purely random in the present experiment, the participants who were led to believe they were highly competent might have found the normative feedback more inconsistent with their expectations.

The additional activation of the parahippocampal gyrus, an area associated with learning and memory processing (Degonda et al., 2005), suggests that the participants with high perceived competence engaged in the retrieval of previous feedback or encoding of the current feedback to monitor their performance at the delivery of the norm-referenced feedback. The norm-referenced feedback also activated the superior parietal lobule among the high-competence group, an area known to be involved in attention (Killgore & Yurgelun-Todd, 2007). Therefore, these highly competent participants appeared to have heightened self-awareness and allocated more attention and memory resources to the norm-referenced than the criterion-referenced feedback, presumably because these participants found the information more consistent with their competence. They might have done so for the purposes of acquiring more accurate competence information, maintaining or validating their superiority.

Assuming that this was actually the case, we would expect these highly competent individuals to feel discontented with the kinds of criterion-referenced performance feedback they received because it presented insufficient information for judging their competence. This supposition is supported by the enhanced activation in the lateral OFC, the posterior cingulate cortex, the anterior cingulate cortex, the medial frontal cortex, and the inferior parietal lobule for the high-competence participants in response to the criterion-referenced feedback (see Fig. 2B). All of these regions are known to be associated with negative affect induced by negative outcomes. For example, this finding is consistent with previous results by Coricelli et al. (2005), who showed that activation in the OFC and the anterior cingulate cortex increased as financial losses mounted. Specifically, previous neuroimaging studies have indicated the lateral OFC to be a region impli-
cated in the punishment processing (O’Doherty et al., 2001) and the anterior cingulate cortex to be associated with negative affect such as pain and distress (Bush, Luu, & Posner, 2000; Matthews, Paulus, Simmons, Nelesen, & Dimsdale, 2004). Note that the posterior cingulate cortex, the medial frontal cortex, and the inferior parietal lobule were the identical areas recruited during norm-referenced feedback for the low-competence group. Thus, the present findings suggest that criterion-referenced feedback, when pitted against norm-referenced feedback, is rather unfavorable for individuals with high competence, whereas the opposite is true for individuals with low competence.

Taken together, the activities in emotion-sensitive brain regions observed in this study suggest that the effects of norm-referenced feedback on affective reactions are moderated by the level of perceived competence. That is, norm-referenced feedback induces negative affect only among individuals with low perceived competence, whereas it results in heightened self-awareness among individuals with high competence. In addition, the involvement of cognitive brain areas, which are responsible for attention and memory, suggests that individuals with high competence find norm-referenced feedback more informative in the sense that it can provide diagnostic information on their competence. For these individuals, criterion-referenced feedback seems to induce negative affect.

9.2. Role of performance-approach goals in feedback processing

Performance-approach goals emerged as another potential moderator of the norm-referenced feedback effect. During the norm-referenced feedback, performance-approach goal scores were positively correlated with the recruitment of differential brain areas implicated in the processing of aversive or threatening stimuli, depending on the level of perceived competence. For the high-competence group, the involvement of the insula, the putamen, the thalamus, and the posterior cingulate cortex, which are modulated by negative feedback or negative affect, suggests that those high in their pursuit of performance-approach goals experi-

Table 3
Brain regions showing significant positive correlations with performance-approach goals in the high-competence group.

<table>
<thead>
<tr>
<th>Brain regions BA</th>
<th>R/L</th>
<th>Talairach coordinates</th>
<th>z-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insula</td>
<td>R</td>
<td>32</td>
<td>16</td>
</tr>
<tr>
<td>Putamen</td>
<td>R</td>
<td>22</td>
<td>-7</td>
</tr>
<tr>
<td>Thalamus</td>
<td>R</td>
<td>6</td>
<td>-19</td>
</tr>
<tr>
<td>Posterior cingulate cortex</td>
<td>31</td>
<td>L</td>
<td>-10</td>
</tr>
<tr>
<td>Precuneus</td>
<td>7</td>
<td>L</td>
<td>-4</td>
</tr>
<tr>
<td>Fusiform gyrus</td>
<td>19</td>
<td>L</td>
<td>-30</td>
</tr>
<tr>
<td>Inferior frontal gyrus</td>
<td>45</td>
<td>R</td>
<td>38</td>
</tr>
<tr>
<td>Superior temporal gyrus</td>
<td>47</td>
<td>L</td>
<td>-46</td>
</tr>
<tr>
<td>Medial frontal gyrus</td>
<td>10</td>
<td>L</td>
<td>-6</td>
</tr>
<tr>
<td>Middle frontal gyrus</td>
<td>6</td>
<td>L</td>
<td>-26</td>
</tr>
<tr>
<td>Superior temporal gyrus</td>
<td>38</td>
<td>R</td>
<td>51</td>
</tr>
<tr>
<td>Middle temporal gyrus</td>
<td>21</td>
<td>L</td>
<td>-61</td>
</tr>
</tbody>
</table>

Note: All regions are significant at \( p < .005 \), uncorrected with an extent threshold of 10 voxels. BA = Brodmann’s area; R/L = right or left hemisphere.

Fig. 3. Brain activation was modulated by each type of feedback across 11 participants of low-competence, with a threshold at \( p < .005 \) (uncorrected). (A) The right posterior cingulate cortex (BA 23), the right medial frontal gyrus (BA 9), and the left inferior parietal lobule (BA 40), were significantly activated during the norm-referenced feedback. (B) The right middle occipital gyrus (BA 19), the left postcentral gyrus (BA 1), and the left superior parietal gyrus (BA 7), were significantly activated during the criterion-referenced feedback.
enced stronger negative affect while processing the norm-referenced feedback. Previous neuroimaging studies on emotional processing have shown that activations in these regions reflect strong negative affect such as anxiety, threat, and distress (Calder, Lawrence, 2002).
feedback. This conjecture makes sense because fear of failure is may experience negative affect upon receiving norm-referenced However, if they hold strong performance-approach goals, they ory because they find norm-referenced feedback more informative. might engage in cognitive processing such as attention and mem-

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It may appear that these findings from the correlation analyses contradict those reported in the subtraction analyses, which did not show negative effects of the norm-referenced feedback for the individuals with high perceived competence. However, these seemingly incompatible reactions during the norm-referenced feedback are conceivable when distinguishing between cognitive and affective processing. Individuals feeling highly competent might engage in cognitive processing such as attention and memory because they find norm-referenced feedback more informative. However, if they hold strong performance-approach goals, they may experience negative affect upon receiving norm-referenced feedback. This conjecture makes sense because fear of failure is one of the consistent antecedents of performance-approach goals evidenced in many survey studies (Conroy, Elliot, & Hofer, 2003; Elliot & McGregor, 2001).

For the low-competence group, activity in the amygdala has been shown to covary with performance-approach goals during the norm-referenced feedback. The role of amygdala in emotional behavior has been widely recognized as appraisal of strong negative emotion, including fear (Adolphs, Tranel, Damasio, & Damasio, 1995; LeDoux, 2003) and aversive conditioning (Buchel, Morris, Dolan, & Friston, 1998). Consistent again with previous survey data, which showed fear of failure as an antecedent of performance-approach goals and a significant positive correlation between performance-approach goals and anxiety (Pekrun, Elliot, & Maier, 2006), this finding suggests that individuals with stronger performance-approach goals, when combined with low perceptions of competence, identify norm-referenced feedback as particularly threatening and fearful.

In sum, our study provides new evidence on the moderating role of perceived competence and performance-approach goals in cognitive and affective reactions during norm-referenced versus criterion-referenced feedback, by revealing differential patterns of brain activation. It seems reasonable to conclude that individuals with prior success to enhance or maintain perceived competence are not as negatively affected by norm-referenced feedback, unless they adopt performance-approach goals. Although performance-approach goals were positively associated with negative affect during the norm-referenced feedback regardless of the level of the experimentally induced perceived competence, the degree of such negative emotional reactions was much more pronounced among the individuals with low perceived competence.

9.3. Implications, limitations, and directions for future research

To our knowledge, this is the first time that the neural correlates of norm-referenced and criterion-referenced feedback have been identified and the moderating effects of perceived competence and performance-approaching goals have been demonstrated. These findings give insights into not only the neural correlates of feedback processing but also implications for classroom assessment of student learning. Given the prevalence of norm-referenced feedback in educational contexts (Black & Wi-

lim, 1998; Shepard, 2000), the costs and benefits of norm-referenced feedback should be assessed more carefully. The present research emphasizes the importance of considering individual learners’ characteristics such as levels of perceived competence and performance-approach goals in optimizing the effects

<table>
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<th>Brain regions showing significant positive correlations with performance-approach goals in the low-competence group.</th>
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<td>Brain regions</td>
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<td>Amygdala</td>
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<td>Norm-referenced &gt; criterion-referenced</td>
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<td>Medial temporal gyrus</td>
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Note: All regions are significant at p < .005, uncorrected with an extent threshold of 10 voxels. BA = Brodmann’s area; R/L = right or left hemisphere.

& Young, 2001). For example, activity in the insula correlates with negative emotions like anxiety, anger, and pain (Damasio et al., 2000); increased activity in both the putamen and the thalamus has also been observed at the delivery of punishment (Knutson, Westdorp, Kaiser, & Hommer, 2000).

The correlation results also indicated that individuals with higher performance-approach goals showed stronger activation in the precuneus known as self-reference area (Cavanna & Trimble, 2006) only when they have high level of competence, suggesting that they might have heightened self-awareness or self-focus during norm-referenced feedback. It is also worthwhile to note that no clear correlation was observed between activation in the precuneus, an area for self-referential processing, and performance-approach goal scores among the low-competence group when the norm-referenced feedback was given. In other words, the individuals with low perceived competence did not show heightened self-awareness during the norm-referenced feedback even if they endorsed performance-approach goals. This finding suggests that self-focus or ego-involvement might not be a universal characteristic associated with performance-approach goals. Rather, it appears to be a characteristic more specifically owing to the combination of performance-approach goals and high perceived competence.

Fig. 5. Significant positive correlation with performance-approach goals were found in the left amygdala of the low-competence participants during the norm-referenced feedback. The scatter plot shows the relationship between performance-approach goal scores and fMRI response (% change in BOLD signal).
of each type of performance feedback. Norm-referenced feedback should be used with caution, especially with learners who are not feeling sufficiently competent, because norm-referenced feedback might produce negative affect. Criterion-referenced feedback, in contrast, may not be as beneficial for learners who are feeling highly competent in terms of their cognition and emotion. Such feedback seems to distract these learners’ attention and induce negative affect because it might provide insufficient information for attaining or maintaining their competence.

On the other hand, it should be noted that negative affect was the prevailing emotional tone even among the highly competent individuals when they pursued strong performance–approach goals. As prior exposure to social comparison encourages adoption of performance–approach goals (e.g., Brophy, 2005; Butler, 1992), which in turn likely increases negative affect when normative feedback is later provided, one should pay a due caution when exercising normative assessment of student performance.

Perhaps the major limitation of this study lies in the problem of ‘reverse inference’, by which the engagement of cognitive or emotional process during a task is inferred from the presence of activation in a particular brain region. However, it is quite common in neuroimaging studies to infer the specific mental processes from the activated brain regions. Although the reverse inference is weak and imperfect from a logical point of view, it is inevitable if the fundamental processing underlying task performance is not known, and it can be useful to elucidate the component processes for a task and to drive subsequent studies if used cautiously (for a more detailed discussion of reverse inference, see Poldrack, 2006, 2008).

Other limitations include the small sample size, which may limit generalizability, the lack of an explicit manipulation check, the artificial nature of the feedback, and the arbitrary range of each type of feedback. Nevertheless, the impact of even such transient manipulation of competence and feedback was quite robust. When we think of real classroom situations where feedback and assessment frequently takes place and possess greater personal significance, we can easily predict much stronger emotional reactions engendered by the feedback provided by classroom teachers.

In terms of future research, we suggest that emotional and motivational consequences of each type of feedback should be investigated further using a multilayered approach, integrating behavioral and psychological data with ongoing changes in brain activation. Because students’ motivation and emotions are linked to academic outcomes and easily swayed by performance feedback, it is important to study the most effective ways to provide feedback that can minimize potentially debilitating emotions such as anxiety, fear, frustration, and depression and overcome emotional challenges. To accomplish this, future studies will need to investigate the precise affective and motivational mechanisms underlying feedback processing with varying timing, specificity, and frequency of diverse types of performance feedback and their interactive effect with individual differences in age, gender, and personality, and so forth.

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