Left Frontal Cortical Activation and Spreading of Alternatives: Tests of the Action-Based Model of Dissonance

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The action-based model of dissonance predicts that following decisional commitment, approach-oriented motivational processes occur to assist in translating the decision into effective and unconflicted behavior. Therefore, the modulation of these approach-oriented processes should affect the degree to which individuals change their attitudes to be more consistent with the decisional commitment (spreading of alternatives). Experiment 1 demonstrated that a neurofeedback-induced decrease in relative left frontal cortical activation, which has been implicated in approach motivational processes, caused a reduction in spreading of alternatives. Experiment 2 manipulated an action-oriented mindset following a decision and demonstrated that the action-oriented mindset caused increased activation in the left frontal cortical region as well as increased spreading of alternatives. Discussion focuses on how this integration of neuroscience and dissonance theory benefits both parent literatures.

Keywords: cognitive dissonance, action-based model, approach motivation, asymmetrical frontal cortical activity, neurofeedback

Inspired by cognitive dissonance theory, hundreds of experiments have demonstrated that following a difficult decision, as compared with an easy one, individuals change their attitudes to be more consistent with their decision (e.g., Harmon-Jones & Mills, 1999; Wicklund & Brehm, 1976). That is, postdecisionally, individuals evaluate the chosen alternative more positively and the rejected alternative more negatively than they did prior to the decision. This effect has been referred to as "spreading of alternatives." However, the original theory of dissonance never clearly specified why cognitive discrepancy caused the negative emotive state of dissonance and why individuals are motivated to reduce dissonance and discrepancy.

Action-Based Model of Dissonance: Why Do Dissonance Processes Occur?

Festinger (1957) posited no answer to the question of why dissonance processes occur other than to state that inconsistency is motivating. Brehm and Cohen (1962), Wicklund and Frey (1981), Beauvois and Joule (1996, 1999), and others pointed out that a behavioral commitment is an important component of the dissonance process and that cognitive inconsistencies without implications for behavior are unlikely to provoke dissonance motivation. However, they did not say why cognitions with implications for behavior motivate persons to engage in discrepancy reductions.

The action-based model of cognitive dissonance was proposed to answer the question, "Why?"(Harmon-Jones, 1999). The action-based model concurs with other areas of psychological research in proposing that perceptions and cognitions can serve as action tendencies. It further proposes that *dissonance between cognitions evokes an aversive state because it has the potential to interfere with effective and unconflicted action*. Dissonance reduction, by bringing cognitions into line with behavioral commitments, serves the function of facilitating the execution of effective and unconflicted action (see also, Jones & Gerard, 1967).

The action-based model proposes both a proximal and a distal motivation for the existence of dissonance processes. The proximal motive for reducing dissonance is to reduce or eliminate the negative emotion of dissonance. The distal motivation is the need for effective and unconflicted action.

Past presentations of the theory of cognitive dissonance have referred to two different constructs as "cognitive dissonance." One is the inconsistency between cognitions. The second is the unpleasant emotional/motivational state that occurs when a person holds two contradictory cognitions. In order to better understand the processes of dissonance, the action-based model distinguishes

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This research was supported by National Science Foundation Grant BCS-9910702. Thanks to Philip Gable, Carly Peterson, and Brandon Schmeichel for helpful comments on an earlier version of this article.

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Journal of Personality and Social Psychology, 2008, Vol. 94, No. 1, 1–15

0022-3514/08/$12.00 DOI: 10.1037/0022-3514.94.1.1

between the two. We refer to inconsistency between cognitions as *cognitive discrepancy*, whereas we refer to the unpleasant emotive state as *dissonance*. The unpleasant emotive state of dissonance provides motivation to change one's attitudes or engage in other discrepancy-reduction processes.

After an individual makes a difficult decision, psychological processing should assist with the execution of the decision. The tendency of participants in dissonance research to view the chosen alternative more favorably and the rejected alternative more negatively after a decision may help the individual to follow through and act on the decision in a more effective manner.

As an example, imagine "Leon," who has been offered jobs with two different companies. The position offered by one company is more intellectually stimulating, but the other company has friendlier coworkers. One company is located in a city with a pleasant climate, but the other is in a city with a reasonable cost of living. Leon sees both job positions as similarly attractive, although they are quite different from each other, and he must decide between them. Once Leon makes a decision, he will need to perform actions in order to follow through with his decision. He will need to relocate, learn new duties, and perform well at them. After his decision, if he continues to see the two positions as similar in attractiveness, he may experience excess regret, which could inhibit him from effectively following through with his decision. However, if Leon is able to reduce dissonance, so that he views the chosen position more positively and the rejected position more negatively, then he will likely perform the job better and be more satisfied. In contrast to models of cognitive dissonance that view dissonance processes as irrational and maladaptive (Aronson, 1969), the action-based model views dissonance processes as adaptive. Of course, adaptive, functional psychological processes that are useful and beneficial in most circumstances may not be beneficial in all circumstances. Occasionally, dissonance reduction may cause persons to maintain a prolonged commitment to a harmful chosen course of action, when it would be better to disengage. However, when we state that dissonance processes are adaptive, we mean that they benefit the organism in the majority of cases. Thus, we propose that, in most cases, effectively following through with behavior after a decision leads to a better outcome than continuing to vacillate about the decision.

Action Orientation and Spreading of Alternatives

The postdecisional state is similar to the action-oriented state (Beckmann & Irle, 1985; Gollwitzer, 1990; Heckhausen, 1986; Kuhl, 1984), in which the individual is in a mode of "getting things done." Once a decision is made, an organism should be motivationally tuned toward enacting the decision and behaving effectively with regard to it. An implemental or action-oriented mindset is one in which plans are made to execute behaviors associated with the decision effectively (Gollwitzer & Bayer, 1999). The individual is in an approach motivational state. When a person is in an action-oriented state, implementation of decisions is enhanced (Gollwitzer & Bayer, 1999).

The action-oriented state is similar to Jones and Gerard's (1967) concept of an unequivocal behavior orientation. They posited that the unequivocal behavior orientation "represents a commitment to action in the face of uncertainty. Such a commitment involves the risks of acting inappropriately, but such risks are assumed to be less grave on the average than the risks of hesitant or conflicted action." (p. 185). They further posited, "When the time comes to act, the great advantage of having a set of coherent internally consistent dispositions is that the individual is not forced to listen to the babble of competing inner forces" (p. 181).

Harmon-Jones and Harmon-Jones (2002) proposed that the action-oriented state that follows decision making is equivalent to the state in which dissonance motivation operates and discrepancy reduction occurs. They hypothesized that experimentally manipulating the degree of action orientation experienced following a decision should affect the degree of discrepancy reduction. In one experiment, participants were asked to make either an easy decision or a difficult decision. Participants were asked to fill out a mindset questionnaire after the decision. The neutral-mindset questionnaire asked participants to list seven things they did in a typical day, whereas the action-oriented mindset questionnaire asked participants to list seven things they could do to perform well on the physical exercise they had chosen. Participants were then asked to reevaluate the exercises. Participants in the difficult-decision, action-oriented condition demonstrated a greater increase in preference for the chosen over the rejected exercise (i.e., spreading of alternatives) than participants in the other conditions.

In a second experiment, Harmon-Jones and Harmon-Jones (2002) replicated the results of the first experiment using a different manipulation of action orientation. In this experiment, action orientation was induced by asking participants to think about a project or goal that they intended to accomplish and to list the steps they intended to use to successfully follow through with their decision (Gollwitzer, 1990). The participants in the action-orientation condition engaged in more spreading of alternatives following a difficult decision than did participants in the comparison conditions. This study replicated the results of the previous study but provided stronger support for the action-based model because the action-orientation induction was unrelated to the decision in the experiment.

Other correlational evidence suggests that action-oriented processing facilitates discrepancy reduction (Beckmann & Kuhl, 1984). In the Beckmann and Kuhl (1984) study, students searching for an apartment were shown information about 16 apartments. The students rated the attractiveness of the apartments before and after choosing the apartment they preferred (i.e., before and after a tentative decision). After the decision, individuals who were dispositionally high in action orientation increased the attractiveness rating of their decision more than did individuals who were dispositionally low in action orientation.

Dissonance and Neural Activity

These previous studies provide support for the action-based model of dissonance (see also Harmon-Jones, Peterson, & Vaughn, 2003). The action-based model suggests which neural circuits are involved in dissonance processes. When dissonance is aroused, it evokes increased sympathetic nervous activity as measured by increased skin conductance (Croyle & Cooper, 1983; Elkin & Leippe, 1986; Harmon-Jones, Brehm, Greenberg, Simon, & Nelson, 1996). Neurally, dissonance should evoke activity in the anterior circulate cortex (ACC), a structure that has been found to be involved in the detection of cognitive conflict. Research has suggested that activity in the ACC is involved in monitoring the occurrence of errors or the presence of response conflict (e.g., Carter et al., 1998; Gehring, Goss, Coles, Meyer, & Donchin, 1993). More important, recent research has found increased ACC activity when behavior conflicts with the self-concept (Amodio et al., 2004). That is, Amodio et al. (2004) found that when individuals who were not prejudiced engaged in behaviors that violated their nonprejudiced self-concept, they evidenced an increase in the amplitude of an event-related brain potential referred to as the error-related negativity, which has been found to be generated by the ACC. This finding suggests that higher level conflicts, the type with which dissonance theory has been most concerned, also activate the ACC.

Once dissonance is aroused or conflict is detected by the ACC, discrepancy reduction can occur rapidly. Indeed, past research has revealed that behavioral commitment itself followed by immediate attitude assessment is sufficient to detect attitude change (Rabbie, Brehm, & Cohen, 1959). Discrepancy reduction engages approach motivational processes, as the individual works to successfully implement the new commitment. This increase in approach motivation should activate the left frontal cortex. Past research suggests that the left frontal cortical region may be involved in approach motivational processes aimed at resolving inconsistency. For example, event-related functional magnetic resonance imaging research has found that the left dorsolateral prefrontal cortex is more active during preparation for color naming than during preparation for word naming in a Stroop task (MacDonald, Cohen, Stenger, & Carter, 2000). Also, more activity in this brain region was associated with less conflict (i.e., smaller reaction time interference effects). MacDonald et al. (2000) suggested that these findings support the hypothesis that the left dorsolateral prefrontal cortex is involved "in the implementation of control, by representing and actively maintaining the attentional demands of the task" (p. 1837). They also suggested that greater activity in the left dorsolateral prefrontal cortex, which implements control, should cause reduced cognitive conflict (see also, van Veen & Carter, 2006).

Other findings obtained from a variety of methodological approaches have suggested that the left and right frontal cortical regions have different motivational functions, with the left frontal region being involved in approach motivational processes, and the right frontal region being involved in withdrawal motivational processes. For instance, Robinson and Downhill (1995) have observed that damage to the left frontal lobe causes depressive symptoms. They have found that for persons with left-hemisphere brain damage, the closer the lesion is to the frontal pole, the greater the depressive symptoms.

The left prefrontal cortex is important for intention, self-regulation, and planning—functions involved in approach motivation and action-oriented processing (Knight & Grabowecky, 1995; Kuhl, 2000; Petrides & Milner, 1982; Tomarken & Keener, 1998). These functions have often been described as properties of the will, a hypothetical construct important in guiding approach-related behavior. Persons with damage to this region are apathetic, experience less interest and pleasure, and have difficulty initiating actions. In addition to data obtained from persons with brain lesions (e.g., Robinson & Downhill, 1995), research assessing electroencephalography (EEG) has found that increased left frontal cortical activation relates to state and trait tendencies toward approach motivation (Harmon-Jones & Allen, 1997, 1998; Sobotka, Davidson, & Senulis, 1992), independent of the valence—positivity or negativity—of the approach motivation (Harmon-Jones, 2003; Harmon-Jones & Allen, 1998; Harmon-Jones & Sigelman, 2001). Moreover, increased left frontal activation relates to trait repression (Tomarken & Davidson, 1994), and high-trait repression has been linked to an increased likelihood of spontaneously reducing dissonance (Olson & Zanna, 1979). Trait repression may be linked to a tendency to engage in positive illusory thinking (Taylor & Brown, 1988), which may be associated with approach motivational tendencies (Taylor & Gollwitzer, 1995).

Experiment 1

On the basis of the preceding analysis, we predict that following commitment to a chosen course of action, relative left frontal cortical activity should be increased, and this increase in relative left frontal cortical activity should be associated with the degree of change in attitudes in support of the chosen course of action. Previous research has revealed that a commitment to a chosen course of action results in the increase of relative left frontal cortical activity (Harmon-Jones, Gerdjikov, & Harmon-Jones, in press). Moreover, this commitment (high-choice) caused attitudes to be more consistent with the behavior, as compared with a low-commitment (low-choice) condition. However, in past research, relative left frontal activation did not relate to attitudes, perhaps because the attitude measure lacked the needed sensitivity (e.g., it did not tap attitude change from precommitment, but only tapped attitudes following the commitment).

In past research, when the psychological process (commitment to a chosen course of action) was manipulated and the proposed physiological substrate was measured (left frontal cortical activation), commitment to a chosen course of action increased relative left frontal cortical activation (Harmon-Jones et al., in press). To provide stronger causal inferences regarding the role of the left frontal cortical region in following through with the commitment (discrepancy reduction), it is important to manipulate the physiology and measure the psychological outcome. Manipulation of the mediator also provides stronger causal evidence than simply correlating the proposed mediator with the outcome (Sigall & Mills, 1998; Spencer, Zanna, & Fong, 2005). In Experiment 1, after participants made a difficult decision, participants' relative left frontal cortical activity was manipulated, and then attitudinal spreading of alternatives was measured.

To manipulate relative left frontal cortical activity, we used neurofeedback training of EEG, also called EEG biofeedback training. Neurofeedback presents the participant with real-time feedback on brainwave activity. The feedback can be presented in the form of a video display, vibration, or sound. If brainwave activity over a particular cortical region changes in the direction desired by the experiment, then the participant is given "reward" feedback; if brainwave activity does not change in the desired direction, then either negative feedback or no feedback is given. Rewards can be as simple as the presentation of a tone that informs the participant that brain activity has changed in the desired way. Neurofeedback-induced changes result from operant conditioning, and as such, these changes in EEG can occur without awareness of how the brain activity changes occurred (Kamiya, 1979; Siniatchkin, Kropp, & Gerber, 2000). This is not to say that it is impossible for a participant to become aware of how she or he caused the changes in brain activity, but research suggests that such awareness requires extensive practice (e.g., 8 weeks of practice; Kotchoubey, Kübler, Strehl, Flor, & Birbaumer, 2002), whereas the changes in brain activity due to conditioning occur much more quickly.

In past research with clinically depressed individuals, neurofeedback training was used to increase relative left frontal activity, and it led to less depression after approximately 27 training sessions (Baehr, Rosenfeld, & Baehr, 2001). In other research with nondepressed individuals, neurofeedback was effective at decreasing but not increasing relative left frontal activity after only 3 days of training. The decrease in relative left frontal activity brought about with this brief neurofeedback training caused less approach-related emotional responses (Allen, Harmon-Jones, & Cavender, 2001). On the basis of these past results, we predicted that the decrease-left frontal condition would be more successful at changing brain activity than the increase-left frontal condition. Although past research with normal individuals revealed that brief neurofeedback failed to increase relative left frontal activity, we included this condition to have a proper neurofeedback comparison condition for the decrease-left condition and to give the increase-left neurofeedback another chance to produce significant brainwave changes.

Most important, we predicted that a decrease in relative left frontal activity would lead to a decrease in discrepancy reduction as measured by spreading of alternatives. To test these predictions, we used the decision paradigm based on the one developed by Brehm (1956).

Method

Overview

Participants underwent 2 days of neurofeedback training designed to increase or decrease relative left frontal cortical activity. On the third day, after making a difficult decision, they underwent another neurofeedback training session of the same direction as previous days (increase vs. decrease left). Finally, participants rerated their decision alternatives. We predicted a manipulated decrease, as compared with increase, in relative left frontal cortical activity would cause a reduction in spreading of alternatives.

Participants and Procedures

Participants were 33 female introductory psychology students who participated in exchange for extra credit toward their grade on Day 1 and then for $10 per hour on Days 2 and 3. On the basis of past research suggesting that neurofeedback of asymmetrical frontal cortical activity produces effects after 3 consecutive days (Allen et al., 2001), participants were administered 3 days of neurofeedback. They were randomly assigned to feedback designed to either increase or decrease relative left frontal cortical activity.

After participants provided informed consent and were prepared for EEG recording on Day 1, their baseline EEG was collected for 8 min. Then, two 8-min blocks of neurofeedback occurred. On Day 2, four 8-min blocks of neurofeedback training occurred. For neurofeedback training, participants were told that the activity of their brains would cause a computer to generate tones and that they should try to make the tone stay on, in order to receive more payment. Participants were not told that neurofeedback was contingent on asymmetry. No explicit verbal feedback was provided to participants concerning their performance.

On Day 3, after the experimenter greeted participants, she explained that the study would examine the relationship between personality characteristics, brain activity, and preferences for different types of psychological research. She also explained that we conduct lots of research in the department but have never asked students how much they would like to participate in such research. She explained that students' preferences for the research may affect their responses in the experiments, so we need to know students' preferences and how personality characteristics related to these preferences. She then said that because the study is short and will last only 20 min, she would have them participate in another study. Then, participants provided informed consent.

The experimenter explained that in the first study, participants would complete short questionnaires that assess preferences for different types of psychological research. The experimenter then shuffled a set of index cards that contained descriptions of nine research projects (attention, attitudes and values, economics, health, law, linguistics, perceptual cognitive, perceptual motor, person perception).

The participants were given the cards and asked to read them in the order in which they were presented and to then rate each project in terms of how desirable it would be to participate in a study like the one described on a 9-point scale (1 = *not at all desirable*, 9 = *very desirable*). Participants were left alone to rate the projects. When the participants informed the experimenter over the intercom that they had completed the ratings, the experimenter returned to the participants' room and asked the participants to rank order the projects on a separate questionnaire. While the participants ranked the projects, the experimenter, who was in the adjacent room, examined the participants' ratings questionnaire and found which two projects had been rated equally and relatively positively (approximately seven on the 9-point scale), as has been done in other research (Brehm, 1956; Harmon-Jones & Harmon-Jones, 2002).

When the participants completed the rankings questionnaire, the experimenter returned to the participants' room and explained that some of the studies that were just rated were being conducted now. She then gave them a choice to participate in one of two studies.

After participants made their decision between two equally rated alternatives, four 8-min neurofeedback training sessions occurred. Then, the experimenter returned to the participant's room with the cards containing the research project descriptions. She explained that we were also interested in how familiarity with the research descriptions might affect ratings of the research projects. She explained that the psychology department was considering posting sign-up sheets that contain more information about the experiments. She explained that if this change occurred, then by the end of the semester, students may have read the names and descriptions of some research projects many times. She further explained that the psychology department wanted us to assess how reading the research descriptions repeatedly affects evaluations of the research. She then asked participants to rate their current preferences for the research projects again.

Afterward, participants completed a questionnaire that asked them to "explain what thoughts, feelings, etc. you had that caused the tone to be played during the biofeedback training session." In the end, the experimenter questioned the participants about suspicion and explained the exact purpose of the experiment.

EEG Recording and Analyses

To record EEG, five electrodes mounted in a stretch-lycra electrode cap (Electro-Cap, Eaton, OH) were placed on the participant's head using known anatomical landmarks (Blom & Anneveldt, 1982). EEG was recorded from midfrontal (F3/4) and parietal (P3/4) regions. The ground electrode was mounted in the cap on the mid-line between the frontal pole and the frontal site. The reference electrode was placed at the vertex (Cz), as done in past frontal asymmetry neurofeedback studies (Allen et al., 2001). Vertical eye movements were recorded from the supra- and suborbit of the left eye to eliminate trials with eyeblinks. All electrode impedances were under 5,000 Ω, and homologous sites (e.g., F3 and F4) were within 1,000 Ω of each other. Electro-Gel (Eaton, OH) was used as the conducting medium. Signals were amplified with J&J Engineering amplifiers (I-410; Poulsbo, WA), bandpass-filtered 1-35 Hz, and sampled at 256 Hz. Alpha power was computed, by bandpass filtering (8–13 Hz) and then rectifying the signals (1-s epochs). EEG alpha power over the frontal cortices is inversely related to activity over the same cortical regions measured using other methods such as positron emission tomography (Cook, O'Hara, Uijtdehaage, Mandelkern, & Leuchter, 1998), functional magnetic resonance imaging (Goldman, Stern, Engel, & Cohen, 2002), and behavioral methods (Davidson, Chapman, Chapman, & Henriques, 1990; Lindsley & Wicke, 1974). Recent source localization work has revealed that approach/withdrawal-related frontal EEG alpha asymmetry reflects dorsolateral prefrontal cortical activity (Pizzagalli, Sherwood, Henriques, & Davidson, 2005).

On Day 1, baseline EEG was acquired for 8 min. After that period, a separate experimenter, who did not interact with the participant, computed the participant's mean frontal difference and standard deviation. This second experimenter was used so that the experimenter who interacted with participants was blind to condition. Then, this second experimenter used the mean and standard deviation to establish a criterion value for the next block of neurofeedback training. The criterion value was the mean of the previous block of EEG recording + 0.85 *SD* for participants in the *increase-left* frontal condition; it was −0.85 *SD* for participants in the *decrease-left* condition. For Day 2, the criterion value was determined from the mean frontal difference and standard deviation of the last 16 min on Day 1. For Day 3, the criterion value was determined from the mean frontal difference and standard deviation from all of Day 2.

Thus, for the neurofeedback training, the computer determined the difference in activity between frontal sites and compared this value against the criterion value established from a previous recording. If the difference exceeded the criterion value in the desired direction, then a tone was played over headphones. If it was not exceeded, then no tone was played. Participants were instructed to attempt to produce the tones. Epochs for which ocular activity exceeded 50 μV resulted in no tone for the next 2 s. Similar to past research (Allen et al., 2001), the criterion values resulted in reinforcement on approximately 20% of trials, and the rate of reinforcement was equivalent across days and groups. In other words, there were no differences between experimental conditions in the participants' abilities to achieve the criterion, and thus, the conditions were equally difficult.

Rationale for Certain Design Issues

The effect of difficult decisions on spreading of alternatives has been demonstrated in hundreds of experiments (for reviews, see Brehm & Cohen, 1962; Festinger, 1964; Harmon-Jones & Mills, 1999; Wicklund & Brehm, 1976). In addition, published experiments found significant spreading of alternatives in difficult but not easy decision conditions, using the same decision paradigm as used in the present experiments (Harmon-Jones & Harmon-Jones, 2002). Thus, following much recent research on spreading of alternatives (e.g., Hoshino-Browne et al., 2005; Steele, Spencer, & Lynch, 1993), we did not include easy decision conditions.

Past neurofeedback studies have not included a "no-feedback" condition because of the difficulties in making no-feedback conditions comparable to neurofeedback conditions (e.g., Allen et al., 2001; Baehr et al., 2001; Hardman et al., 1997; Roberts, Birbaumer, Rockstroh, Lutzenberger, & Elbert, 1989). To be comparable to neurofeedback conditions, a no-feedback condition would need to include "feedback" tones, and participants would need to be told that their brainwaves were producing the tones. It is likely that such sham feedback and instructions will not be neutral to participants. Because of the robustness of the spreading-of-alternatives effect following difficult decisions in "neutral" conditions, we did not include a no-neurofeedback-training condition in the present experiment. If the neurofeedback-induced manipulation of relative left frontal activity caused differences in spreading of alternatives, then the results would support the predictions derived from the action-based model. The question of whether the neurofeedback training caused increased versus decreased spreading of alternatives relative to a no-feedback condition was not important for the test of this theory-derived prediction. Rather, the question we wanted to address was, "Does a manipulated change in frontal asymmetry affect the degree of dissonance reduction?" Also, given the concerns about the difficulty of creating a comparable no-feedback condition, such a condition was not included.

Results

The manipulation of relative left frontal activation was successful. On Day 3, the decrease-left frontal group showed less left frontal cortical activity ($M = -0.187$, $SD = 0.329$) than the increase-left frontal group ($M = 0.017$, $SD = 0.156$); analysis of covariance [ANCOVA] controlling for Day 1 baseline, $F(1, 30) = 4.48$, $p = .04$, partial $\eta^2 = .13$. An ANCOVA was performed so that individual differences in baseline (Day 1) relative left frontal activity could be statistically controlled. A one-way analysis of variance (ANOVA) without the use of the baseline covariate was also significant, $F(1, 31) = 5.29$, $p = .03$, partial $\eta^2 = .15$.

In the condition in which participants received neurofeedback to decrease left frontal cortical activity, there was a significant decrease in spreading of alternatives, as revealed in a significant 3-way (Neurofeedback Condition × Pre vs. Postdecision × Chosen vs. Rejected) interaction, $F(1, 31) = 4.23$, $p < .05$, partial $\eta^2 = .12$. That is, within the decrease-left frontal condition, no significant spreading of alternatives occurred, as revealed in a nonsignificant 2 (pre- vs. postdecision) × 2 (chosen vs. rejected alternative) within-subjects ANOVA, $F(1, 15) = 0.26$, $p = .62$, partial $\eta^2 = .02$. However, within the increase-left frontal condition, significant spreading of alternatives occurred, $F(1, 16) = 10.97$, $p = .004$, partial $\eta^2 = .41$. See Figure 1.

Another way to examine the attitude effects is to separately test for changes in attitudes toward chosen alternatives and then rejected alternatives. For chosen alternative attitudes, a 2 (condition) × 2

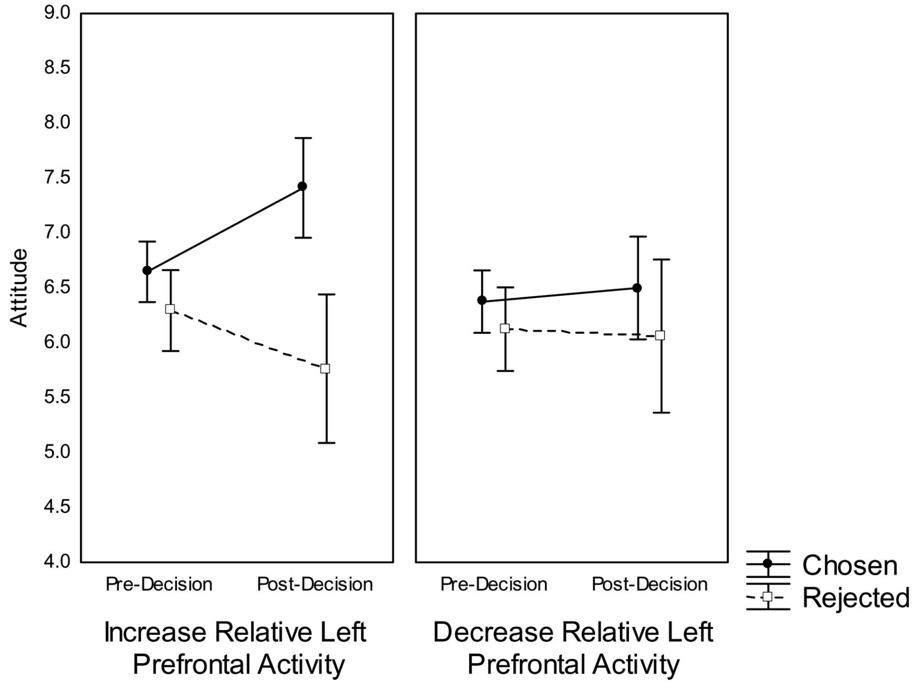

Figure 1. Attitudes toward chosen and rejected decision alternatives pre- and postdecision, as a function of neurofeedback condition. Error bars reflect ± 1 standard error.

(predecision vs. postdecision) ANOVA produced a significant interaction, $F(1, 31) = 5.73$, $p < .03$, partial $\eta^2 = .16$. Within the increase-left frontal condition, the chosen alternative was evaluated more positively following the decision ($p < .01$), whereas within the decrease-left frontal condition, the chosen alternative was not evaluated differently from pre- to postdecision ($p > .40$). A similar ANOVA conducted on evaluations of the rejected alternatives produced a nonsignificant interaction, $F(1, 31) = 1.06$, $p > .30$. Exploratory follow-up tests revealed that within the increase-left frontal condition, attitudes toward the rejected alternative became more negative following the decision ($p < .04$, one-tailed), whereas within the decrease-left frontal condition, attitudes toward the rejected alternative did not change ($p > .70$).

Neurofeedback training of relative left frontal activity did not produce significant effects in the parietal region, as revealed in a nonsignificant ANOVA, with neurofeedback-training condition as the independent variable and parietal asymmetry as the dependent variable ($F < 1.0$). This result, in conjunction with past results (Harmon-Jones et al., in press), suggests that it is specifically the left frontal regions that are involved in discrepancy reduction.

Correlational Analyses

Correlations between spreading of alternatives and relative left frontal activation were examined to test whether the two variables were related. It was expected that the greater the relative left frontal activation, the greater the spreading of alternatives. Across both conditions, spreading of alternatives was positively related to relative left midfrontal activity ($r = .40$, $p < .01$, one-tailed). When each condition was examined separately, this positive relationship between spreading of alternatives and relative left frontal activity occurred, but it was not quite significant in either condition, perhaps because of the small sample size (increase left $r = .40$, $p < .06$, one-tailed; decrease left $r = .30$, $p = .13$, one-tailed).

Awareness of the Neurofeedback Learning Process

Participants' open-ended responses to the questionnaire asking them what thoughts and feelings caused the tone to be played were analyzed to explore whether participants' conscious thoughts and feelings were related to the neurofeedback training. Two independent raters blind to condition and other data evaluated the open-ended responses. Agreement was greater than 90% and resolved through discussion. Participants gave a variety of responses. Some indicated that they did not know what caused the tone to be played. Some indicated that not thinking about the tone helped, whereas others indicated that thinking about the tone helped. In addition, participants described memories, songs, decisions, plans, letting their minds wander, and relaxation as techniques that produced the tones. These reports did not differ between conditions or relate significantly to relative left frontal activation. The reports were also scored for the amount of approach motivation, avoidance motivation, positive affect, and negative affect reported (1 = *not at all* and 5 = *extremely*). No differences between conditions resulted. Across conditions, relative left frontal activity was negatively correlated with avoidance motivation ($r = -.34$, $p = .05$) and positively correlated, albeit nonsignificantly, with approach motivation ($r = .24$, $p = .18$). No other correlations were significant. We also examined whether reports of motivation affected spreading of alternatives by conducting a regression analysis in which spreading was predicted by condition, approach ratings, and avoidance ratings. Only condition was a significant predictor ($\beta = .40$, $p = .03$); all other predictors were nonsignificant ($ps > .10$).

Discussion

In support of predictions, Experiment 1 revealed that neurofeedback training caused a reduction in relative left frontal cortical activity, which caused an elimination of the familiar spreading-of-alternatives effect. These results are consistent with the action-based model of dissonance, which suggests that following commitment to a chosen course of action, approach-oriented motivational processes are engaged to assist with the execution of the decision. Together with past research showing that commitment to a chosen course of action increases activity in the left frontal cortex (Harmon-Jones et al., in press), the present experiment's manipulation of relative left frontal cortical activity, a presumed mediator of the effect of commitment on discrepancy reduction, provides strong support for the role of the left frontal cortex in discrepancy reduction processes.

As noted earlier, neurofeedback-induced changes in the brain often occur without conscious awareness of the process. In general, the analyses of the open-ended responses were consistent with this past research. However, some evidence suggested that participants who wrote more avoidance-oriented (less approach-oriented) descriptions evidenced lesser relative left frontal activation. These findings are consistent with the motivational direction model of asymmetrical frontal cortical activity, but the direction of causation (if one exists) is difficult to determine. It is possible that the neurofeedback-induced change in frontal asymmetry caused the motivationally relevant "thoughts." In contrast, the thoughts may have caused the changes in frontal asymmetry. In a direct test of this latter idea, Hardman et al. (1997) assigned participants to a strategy versus no-strategy condition prior to neurofeedback training of asymmetrical frontal cortical activity. In the strategy condition, participants were instructed to think happy (sad) thoughts as neurofeedback training occurred to increase left (right) frontal cortical activity. Results indicated that both groups learned, with the no-strategy group learning better than the strategy group. Although these results suggest that it is unlikely that participants used emotional strategies to alter frontal EEG asymmetry, there remain two possible explanations for how frontal EEG asymmetry was altered. The first is that participants used some other strategy that did not focus on emotions but that might plausibly impact asymmetry in accord with predictions of the approach–withdrawal model. The second alternative, and one that would be difficult to establish conclusively, is that the neurofeedback training impacted frontal EEG asymmetry directly, without the use of such intervening strategies. The significance of the present results do not hinge on accepting one or the other of these alternatives. Either explanation supports the conclusion that altering frontal asymmetry, either directly or indirectly, produces changes in postdecisional spreading of alternatives.

Experiment 2

Experiment 2 was designed to conceptually replicate Experiment 1. Given the time-consuming and costly nature of neurofeedback training, in Experiment 2, we used a different manipulation to alter relative left frontal cortical activity and to more specifically test the hypothesis that changes in the degree of relative left frontal cortical activity would affect attitudinal spreading of alternatives following commitment to a chosen course of action. In Experiment 2, we tested this hypothesis by manipulating action-oriented processing following a difficult decision. We expected to replicate past research that showed that the action-oriented mindset would increase discrepancy reduction following a decision (Harmon-Jones & Harmon-Jones, 2002). Second, we expected that the action-oriented mindset would increase relative left frontal cortical activity. Finally, we expected that this increase in left frontal cortical activity would relate to discrepancy reduction, as assessed by spreading of alternatives.

To further extend past research, we included a condition to manipulate positive affect that was low in approach motivation. This was done to distinguish between the effects of positive affect and of approach motivation on spreading of alternatives. Past research suggested that action-oriented mindsets increase positive affect (Taylor & Gollwitzer, 1995), but we do not predict that positive affect, itself, causes increased left frontal cortical activity or an increase in spreading of alternatives. Thus, the design and predicted results for Experiment 2 would rule out an alternative explanation of past research. According to this explanation, more spreading of alternatives might have occurred in the action-oriented condition because persons in this condition felt more positive affect, and this positive affect may have provided resources that assisted in discrepancy reduction. By demonstrating that a low-approach positive affect manipulation does not cause an increase in spreading of alternatives, the predicted results of Experiment 2 would eliminate this alternative explanation.

Method

Overview

Participants made a decision between two equally attractive alternatives (difficult decision). They were then randomly assigned to complete a questionnaire that induced an action-oriented, positive nonaction-oriented, or neutral mindset. Next, EEG was collected, and then participants reported their affective states. Finally, participants rerated their decision alternatives. We predicted that greater spreading of alternatives would occur in the action-oriented condition as compared with the other conditions. Also, we predicted that the action-oriented condition would cause greater relative left frontal activity than the other conditions.

Participants

Fifty-seven (16 men and 41 women) students participated in exchange for extra credit in their introductory psychology course.[1]

[1] Experiment 1 comprised only women because more women were available as possible participants when the experiment was conducted, and we wanted to avoid any condition imbalances in gender in this labor-intensive experiment. In Experiment 2, participants were not selected for gender, but most were women because there were more women in introductory psychology. Past research with large gender-balanced samples on asymmetrical frontal cortical activity and motivation (Harmon-Jones, Sigelman, Bohlig, & Harmon-Jones, 2003) and on spreading of alternatives (Harmon-Jones & Harmon-Jones, 2002) has revealed no gender differences. Thus, past research suggests that gender differences would not have emerged in the present research had more gender-balanced samples been available.

Participants were randomly assigned to one of three conditions: action oriented, positive nonaction oriented, or neutral mindset.

Procedure

The procedure for creating and assessing the spread of alternatives was identical to Experiment 1. Participants were asked to rate their preferences for experiments in which they might participate. Then, they were asked to choose between two experiments that they had rated positively and similarly in attractiveness.

After the participants chose the experiment in which they would like to participate, the experimenter explained that she needed to prepare the materials and computer for the next study. She asked participants to complete the personality questionnaires, which she presented as part of the "first study" on personality and preferences for different types of research. The experimenter handed the participants an envelope that contained the personality questionnaires and asked the participants to return them to the envelope when the questionnaires were completed. The "personality questionnaires" constituted the mindset manipulation and were presented in an envelope to keep the experimenter blind to condition.

After the questionnaires were completed, the experimenter asked participants to sit still and think about the information they gave in the questionnaires for 3 min while their EEG was recorded. Then, the experimenter asked the participants to complete another questionnaire, which assessed affect. Finally, participants rerated all of the experiments, as in Experiment 1.

Mindset manipulation. For the mindset manipulation, participants were randomly assigned one of three questionnaires. Each questionnaire, labeled *The Projective Life Attitudes Assessment*, explained that the assessment was an innovative personality assessment and that descriptions about aspects of life tell us a considerable amount about personality. It was explained that the responses to this survey would be content analyzed to assess dimensions of personality.

In the neutral-mindset condition, participants were told to think about an ordinary day in their life. They were asked to describe the day in enough detail so as to cover the space allotted. They were asked to select a typical day in which an extremely positive or negative event did not occur.

In the action-oriented mindset condition, participants were instructed to think about an *intended project*, defined as a project that has a goal that they intend to accomplish someday. They were informed that the intended project should be one in which they have decided to take action. They were asked to write about a project that was complex but could be achieved within the next 3 months. They were to list the project; the five most important steps to bring about this project; and when, where, and how each step will be performed (Taylor & Gollwitzer, 1995).

In the positive-nonaction-oriented mindset condition, participants were instructed to think about a day or time when something happened that caused them to feel very good about themselves (e.g., a special time with loved ones, friends, and the like). They were instructed to describe an event

> that happened to you and *not* one that resulted from something you did. An example would be a time when someone did something wonderful for you. Think about this exceptional time and describe it in enough detail so as to cover the space allotted on the following pages. Select an exceptionally positive time in which something happened to you that made you feel very good about yourself.

Affect questionnaire. Items were included to assess positive affect (enthusiastic, interested, happy, proud, feel good about myself; Cronbach's $\alpha = .78$) and negative affect (uncomfortable, tense, displeased with myself, uneasy, unsure; Cronbach's $\alpha = .81$). Participants were instructed to indicate how they felt right now (1 = *not at all*; 5 = *extremely*).

EEG Recording and Analyses

EEG was recorded from 27 (22 homologous and 5 midline) electrodes mounted in a stretch-lycra electrode cap (Electro-Cap, Eaton, OH). EEG was recorded from the frontal, central, temporal, parietal, and occipital regions (and regions in between) using the 10% electrode system (Chatrian, Lettich, & Nelson, 1985). The ground electrode was mounted in the cap on the midline between the frontal pole and the frontal site. The reference electrode was placed on the left ear (A1), and data were also acquired from an electrode placed on the right ear (A2) so that an offline digitally derived, averaged ears' reference could be computed. Eye movements were also recorded using an electrooculogram (EOG) to facilitate artifact scoring of the EEG. EOG was recorded from the supra- and suborbit of the left eye, to assess vertical eye movements, and from the left- and right-outer canthus, to assess horizontal eye movements. All electrode impedances were under 5,000 Ω, and homologous sites (e.g., F3 and F4) were within 1,000 Ω of each other. Electro-Gel (Eaton, OH) was used as the conducting medium. EEG and EOG were amplified with Neuroscan Synamps (Herndon, VA), bandpass filtered (0.1–100 Hz; 60-Hz notch filter enabled), digitized at 500 Hz, and stored onto a computer hard drive. Prior to running each participant, to assess the technical integrity of the recording system, 400 microvolts 20-Hz calibration signals were run and inspected.

The EEG and EOG signals were visually scored on a high-resolution computer monitor, and portions of the data that contained eye movements, muscle movements, or other sources of artifact were removed. When artifact occurred in one channel at a point in time, data from all channels were removed at that point in time. Derived averaged-ears reference data were used for further data reduction, as past research has found it to be an appropriate reference (Hagemann, Naumann, Becker, Maier, & Bartussek, 1998). All artifact-free epochs that were 2.048 s in duration were extracted through a Hamming window, which was used to prevent spurious estimates of spectral power. Contiguous epochs were overlapped by 75% to minimize loss of data due to Hamming window extraction. A fast Fourier transform was used to calculate the power spectra. These power values were averaged across the 2.048-s epochs of a given trial. Total power within the alpha (8–13 Hz) frequency range was obtained. The power values were log transformed for all sites to normalize the distributions.

Asymmetry indexes (natural log right − natural log left alpha power) were computed for all homologous sites (Fp1/2, F3/4, F7/8, Ft7/8, Fc3/4, T3/4, T5/6, C3/4, Cp3/4, P3/4, O1/2) for the 3 min following the mindset manipulation. Because alpha power is inversely related to cortical activity, higher scores on the indexes indicate greater relative left-hemisphere activity.

Results

Two independent raters read and evaluated each response to the mindset manipulation. They agreed completely. All participants correctly followed the instructions for their mindset condition.

Spreading of Alternatives

To test the effects of mindset manipulation on *attitudes*, a 3 (mindset) between-participants × 2 (predecision vs. postdecision) × 2 (chosen vs. rejected alternative) within-participants ANOVA was performed. It produced the critical three-way interaction, $F(2, 54) = 3.19$, $p < .05$, partial $\eta^2 = .11$; see Figure 2. To decompose this interaction, 2 (predecision vs. postdecision) × 2 (chosen vs. rejected alternative) within-participants ANOVAs were conducted within each between-participants condition. First, it is important to note that the spreading of alternatives occurred within the neutral-mindset condition, as demonstrated by a significant 2 (predecision vs. postdecision) × 2 (chosen vs. rejected alternative) interaction, $F(1, 19) = 7.25$, $p < .02$, partial $\eta^2 = .28$. Second, spreading of alternatives also occurred within the action-oriented mindset condition interaction, $F(1, 17) = 76.58$, $p < .001$, partial $\eta^2 = .81$. Finally, significant spreading of alternatives occurred within the positive-nonaction mindset condition interaction, $F(1, 17) = 11.77$, $p < .003$, partial $\eta^2 = .40$.

The above interactions were followed up by examining the attitude change toward the chosen and rejected alternatives within each between-subjects condition. Within the neutral condition, attitudes toward the chosen alternative did not change from pre- to postdecision, but attitudes toward the rejected alternative did change ($p < .01$). Within the action-oriented mindset condition, attitudes toward the chosen alternative and attitudes toward the rejected alternative changed ($ps < .01$). Finally, within the positive-nonaction mindset condition, attitudes toward the chosen alternative did not change from pre- to postdecision, but attitudes toward the rejected alternative did change ($p < .01$).

Another way to follow up the above 3-way interaction is to examine attitude change toward the chosen (or rejected) alternative between conditions. For the chosen alternative, a 3 (condition) × 2 (predecision vs. postdecision) ANOVA produced a significant interaction, $F(2, 54) = 5.94$, $p < .005$, partial $\eta^2 = .18$. Attitudes toward the chosen alternative changed significantly from pre- to postdecision only within the action-oriented mindset condition ($p < .01$). For the rejected alternative, a similar ANOVA was conducted, but the interaction was not significant, $F(2, 54) = 0.50$. Follow-up simple-effects tests to explore the pattern of means revealed that the action-oriented mindset caused more derogation of the rejected alternative than the positive-nonaction-oriented condition ($p < .05$, one-tailed), but not the neutral condition ($p > .18$).

We next analyzed the spreading-of-alternatives index (difference in postdecision attitudes − difference in predecision attitudes), using a planned comparison, in which the action-oriented condition was pitted against the other two conditions (2, −1, −1). It was significant, $F(1, 54) = 6.37$, $p < .02$, partial $\eta^2 = .11$. More spreading of alternatives occurred in the action-oriented mindset condition ($M = 2.72$, $SD = 1.32$) than in other conditions (neutral $M = 1.40$, $SD = 2.33$; positive nonaction $M = 1.37$, $SD = 1.74$;

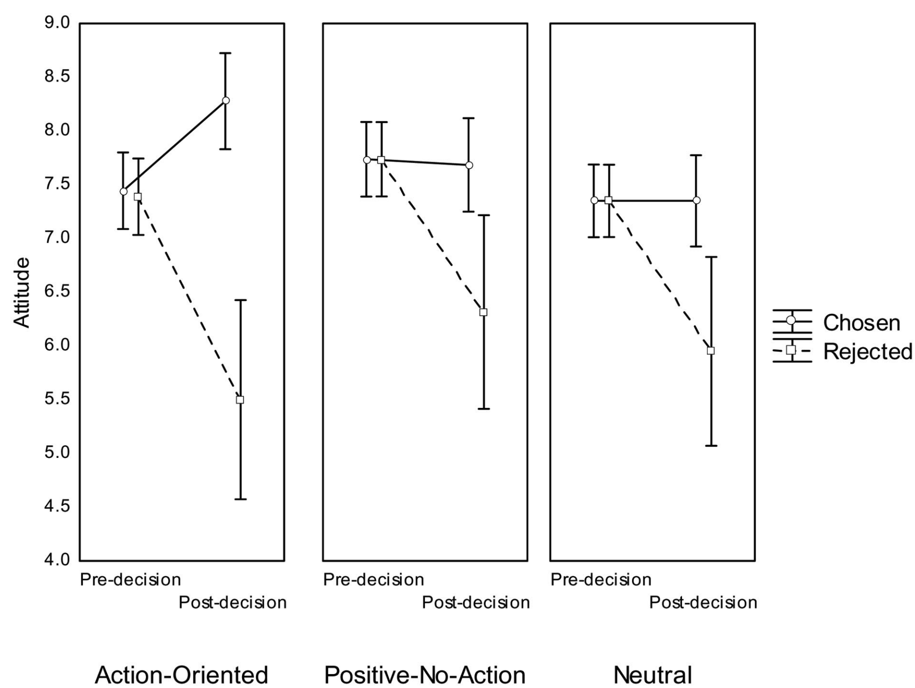

Figure 2. Attitudes toward chosen and rejected decision alternatives pre- and postdecision, as a function of mindset condition. Error bars reflect ± 1 standard error.

all *p*s $< .04$). The latter two conditions did not differ from each other on spreading of alternatives ($p > .90$).[2]

Self-Reported Affect

The effects of the mindset manipulation on each affect index were tested in separate analyses. For positive affect, a planned comparison that pitted the action-oriented and positive-nonaction conditions against the neutral condition (1, 1, −2) was conducted, and it was significant, $F(1, 54) = 13.47$, $p < .001$, partial $\eta^2 = .24$. It indicated that the action-oriented ($M = 2.99$, $SD = 0.77$) and positive-nonaction mindsets ($M = 3.41$, $SD = 0.76$) evoked more positive affect than did the neutral-mindset condition ($M = 2.51$, $SD = 0.48$; all *p*s $< .04$). For negative affect, a one-way ANOVA was conducted because there were no a priori predictions. The ANOVA was not significant ($p > .75$; *M*s ranged from 1.70 to 1.85).

Cortical Activation

We predicted that the action-oriented mindset condition, as compared with the other conditions, would cause greater relative left midfrontal activation because past research has implicated this region in approach-motivational processes (see Experiment 1; for a review, see Coan & Allen, 2004). A planned comparison for midfrontal sites (F3, F4) pitting the action-oriented mindset condition against the other two conditions was significant, $F(1, 54) = 7.07$, $p < .02$, partial $\eta^2 = .12$. Each condition differed from the action-oriented mindset condition (*p*s $< .05$). Because some past research has also suggested that lateral frontal regions may be involved in motivational processes, a similar planned comparison for lateral frontal sites (F7, F8) was conducted. It was also significant, $F(1, 53) = 8.08$, $p < .01$, partial $\eta^2 = .14$. Each condition differed from the action-oriented mindset condition (*p*s $< .04$).

All other possible asymmetries were evaluated using one-way ANOVAs, and all were nonsignificant (*p*s $> .06$), except for frontal central sites (FC3, FC4), $F(2, 50) = 3.38$, $p < .05$, partial $\eta^2 = .12$. This significant effect revealed that the action-oriented condition differed from the neutral condition ($p < .02$) and that the positive-nonaction condition was between the other two conditions and not different from either one (*p*s $> .14$). See Table 1 for means and standard deviations for the significant effects.

Table 1
Means and Standard Deviations for Asymmetries at Frontal Sites

	Action oriented		Positive no action		Neutral	
Variable	*M*	*SD*	*M*	*SD*	*M*	*SD*
Midfrontal (F3, F4)	0.082	0.103_a	0.022	0.066_b	0.008	0.093_b
Lateral frontal (F7, F8)	0.027	0.167_a	−0.072	0.115_b	−0.100	0.128_b
Frontal central (FC3, FC4)	0.068	0.155_a	−0.014	$0.146_{a,b}$	−0.078	0.186_b

Note. More positive scores reflect greater left than right-hemispheric activity. Within rows, means with different subscripts are significantly different from one another at $p < .05$.

Within-condition correlations between spreading of alternatives and relative left frontal activation were examined to test whether the two variables were positively related within the action-oriented condition. Within the action-oriented mindset condition, spreading of alternatives was positively related to relative left midfrontal activity ($r = .72$, $p < .01$). Within the other two conditions, no significant associations of spreading of alternatives and relative left frontal activity emerged (positive nonaction $r = -.28$; neutral $r = .29$; *p*s $> .20$). These latter correlations do not significantly differ from zero and are thus difficult to interpret. This is not surprising because, in these conditions, participants were instructed to think of neutral and positive-nonaction information, and thus these EEG measurements do not directly reflect neural activity associated with postdecision processing. In contrast, participants in the action-oriented mindset condition were instructed to think about information that should facilitate dissonance reduction, according to the action-based model and previous research (Harmon-Jones & Harmon-Jones, 2002).

Discussion

Results from Experiment 2 were consistent with predictions and revealed that the action-oriented mindset increased relative left frontal cortical activity and spreading of alternatives. These results provide a conceptual replication of the results of Experiment 1 by using a different operationalization of action-oriented motivational processing. Both experiments revealed that the hypothesized increase in action-oriented processing was manifested in increased relative left frontal cortical activity.

These results extend past research on the action-based model in two important ways. First, although previous studies have shown that commitment to a chosen course of action, as compared with a no-choice condition, increases relative left frontal cortical activity and dissonance-related attitude shifts (Harmon-Jones et al., in press), the present results show that manipulation of the presumed psychobiological process—action-oriented processing/relative left frontal cortical activity—increases attitudinal shifts in support of the chosen course of action. Second, the results of Experiment 2 suggest that Experiment 1's neurofeedback-induced changes in relative left frontal activity was likely due to the effect of that brain region's alteration on action-oriented processing, albeit without participant awareness. That is, when taken together with past research, the results of the present two experiments strongly suggest that the process of dissonance reduction following commitment is due to action-oriented processing, which is evident in relative left frontal cortical activation. Other neural structures, chemicals, and mechanisms are likely involved in action-oriented processing, but the present results suggest that at least relative frontal cortical activation is involved.

[2] As predicted, the decrease-left frontal condition eliminated spreading of alternatives. This was established by comparing spreading in the decrease-left frontal condition from Experiment 1 with the spreading in the neutral condition from Experiment 2. That is, spreading of alternatives in the decrease-left condition of Experiment 1 was smaller than spreading of alternatives in the neutral condition of Experiment 2, $t(33) = 2.15$, $p < .04$. This result suggests that the decrease-left condition not only eliminated significant spreading of alternatives but also caused less spreading of alternatives than a neutral condition.

Another way to examine the effect of relative left frontal cortical activity on spreading of alternatives is to conduct the regression analyses suggested by Baron and Kenny (1986). In both of the present experiments, the first two conditions suggested by Baron and Kenny (1986) were met; that is, condition predicted relative left frontal activity and spreading of alternatives. In Experiment 1, when condition (effect coded) and relative left frontal activity were entered to predict spreading of alternatives simultaneously, relative left frontal activity emerged as a marginally significant predictor (β = .32, p = .08, two-tailed), whereas condition was not a significant predictor (β = .23, p = .21). In Experiment 2, when condition (effect coded) and relative left frontal activity (F3, F4) were entered to predict spreading of alternatives simultaneously, relative left frontal activity emerged as a significant predictor (β = .26, p = .05), whereas condition was marginally significant (β = .24, p = .08). These results provide some, albeit weak, evidence for partial *statistical* mediation, even though these experimental designs lacked power because of their small sample sizes.

The above pattern of results is consistent with much past research on dissonance and mediating variables. When researchers have sought evidence of the statistical mediating effect of emotion/motivation variables on dissonance reduction, the evidence has generally been nonsupportive (for a review, see Harmon-Jones, 2000b). For instance, studies have failed to demonstrate that self-reported negative affect or electrodermal activity mediates the relationship between choice and attitude change (Elliot & Devine, 1994; Harmon-Jones, 2000a; Harmon-Jones et al., 1996; Higgins, Rhodewalt, & Zanna, 1979). However, in spite of the fact that statistical mediation has not been demonstrated, it is well accepted that dissonance-produced negative affect does indeed mediate the relationship of choice and attitude change. The research supporting this mediation is based not on statistical mediation but on experimental mediation of two forms. First, research using the misattribution paradigm has found that the opportunity to misattribute negative affect to a stimulus other than dissonance reduced the attitude change following freely choosing to engage in counterattitudinal behavior (e.g., Higgins et al., 1979; Zanna & Cooper, 1974). Second, other research has revealed that increasing negative affect through independent means (e.g., frowning) increases attitude change following counterattitudinal behavior and that decreasing negative affect/increasing positive affect decreases attitude change following counterattitudinal behavior (e.g., Kidd & Berkowitz, 1976; Rhodewalt & Comer, 1979; Steele, Southwick, & Critchlow, 1981). Why experimental mediation produces more favorable evidence than statistical mediation for the predicted mediational processes is presently unknown, but it may be due to the drawbacks of statistical mediation discussed by Spencer et al. (2005).

General Discussion

The results of the present experiments support the action-based model of dissonance that predicts that the process of dissonance reduction involves an approach-related action orientation that is instantiated in relative left frontal cortical activity. Experiment 1 provided evidence that the relative left frontal activation was causally involved in the spreading-of-alternatives effect, as manipulation of relative left frontal activation affected the degree of spreading of alternatives (Sigall & Mills, 1998). Experiment 2 provided evidence supportive of the idea that action orientation increased left frontal cortical activity and spreading of alternatives.

Asymmetrical Frontal Cortical Activity

In addition to supporting predictions derived from the action-based model, the present experiments enhance researchers' understanding of the left prefrontal cortex and its role in the implementation of intentions, as it demonstrates that left prefrontal cortical activity is involved in the attitude change following decisions.

The results of Experiment 1 provide further evidence that neurofeedback training can be used to alter asymmetrical frontal cortical activity and that such alterations have consequences for motivational processes such as cognitive discrepancy reduction. This is the first demonstration that neurofeedback training of asymmetrical frontal cortical activity has effects on cognitive-motivational variables other than those more directly related to emotional expression such as depression (Baehr et al., 2001) and facial muscle responses to affective film clips (Allen et al., 2001).

The results of Experiment 2 suggest that positive affect per se is not related to relative left frontal activation. Instead, approach motivation, which in the present experiment was associated with a certain kind of positive affect, is related to relative left frontal activation. This result adds to a growing body of research challenging the idea that asymmetrical frontal cortical activity is associated with affective valence (where left frontal activity is posited to be related to positive affect, and right frontal activity is posited to be related to negative affect; see, e.g., Heller, Nitschke, & Miller, 1998). The present research provides convergent evidence that asymmetrical frontal cortical activity is associated with motivational direction (approach motivation), not affective valence (positive affect). Previous research has shown that approach-oriented anger, which is negative in valence, is related to greater relative left frontal activation (for a review, see Harmon-Jones, 2003). Experiment 2's results extend this previous work by showing that positive affect low in approach motivation does not increase relative left frontal activation, but positive affect high in approach motivation does.

We have suggested that the observed increase of left frontal cortical activity reflects approach-related action orientation. This interpretation is consistent with much research (see reviews by Coan & Allen, 2004; Harmon-Jones, 2003, 2004; Pizzagalli, Shackman, & Davidson, 2003). It is possible that an approach-related action orientation at this cortical level reflects both the strengthening of the approach action tendencies and the inhibition of action tendencies that would interfere with the execution of the action. Past research showing that approach-oriented anger is associated with greater relative left frontal cortical activity is consistent with this possibility, as approach-oriented anger often involves the suppression of fear and anxiety (van Honk & Schutter, 2006, 2007), emotions that would interfere with angry behavior.

Along these lines, the evidence gathered to date on dissonance reduction, approach motivation manipulations, and relative left frontal cortical activations provides evidence for both the selective strengthening of the chosen alternative and inhibition or derogation of the rejected alternative. In the Harmon-Jones and Harmon-Jones (2002) experiments, it was observed that the attitude change caused by an action-oriented mindset was primarily increased derogation of the rejected alternative. In the Harmon-Jones et al.

(in press) experiment, the high-choice manipulation caused increased left frontal cortical activation and attitude change primarily toward the negative aspects of the attitudinal issue; that is, high-choice participants, as compared with low-choice participants, evaluated an increase in tuition as less bad and unfair but not more wise and favorable. In the present research, both experiments suggested that the manipulations of action-oriented processing primarily influenced attitudes toward the chosen alternative. According to the original theory of dissonance, one or both attitude change processes can occur to reduce dissonance. Past research has demonstrated that both types of processes occur (e.g., Wicklund & Brehm, 1976). However, it is unclear when changes toward the chosen or changes toward the rejected or both types of changes will occur. One experiment has suggested that the initial attitude toward the alternatives will influence the direction of change (Shultz, Leveille, & Lepper, 1999). It is also likely that other variables, such as importance of the decision alternatives and resistance to change of the alternatives, will play a role. Future research will need to explore these issues.

Left frontal activity is not only associated with approach motivational processes. Other studies have found that left frontal activity is associated with language, semantic memory retrieval, and episodic memory encoding (Cabeza & Nyberg, 2000). However, it does not seem plausible that these cognitive processes provide alternative explanations for why action orientation increases left frontal activity and why the same orientation causes greater attitude change in support of the behavior. Moreover, the reduction of these cognitive processes via neurofeedback-induced deactivation of relative left frontal activation would not be predicted to decrease spreading of alternatives.

Other Modes of Dissonance Reduction

Would a change in relative left frontal cortical activity affect discrepancy reduction in other dissonance-evoking situations? We would expect left frontal cortical activity to affect dissonance processes when dissonance is aroused by a strong commitment to behavior, which is what typically occurs in the induced compliance and free-choice paradigms (e.g., Beauvois & Joule, 1996; Brehm & Cohen, 1962). In such situations, we predict that individuals are motivated to follow through with their behavioral commitment and to change their attitudes to be consistent with their behavior (Stone, Wiegand, Cooper, & Aronson, 1997). However, in some induced compliance situations, individuals may reduce dissonance by means other than attitude change, perhaps because their commitment is not sufficiently strong or because their original attitude is highly resistant to change (Simon, Greenberg, & Brehm, 1995). Thus, in other dissonance paradigms, we would predict relative left frontal activation to relate to dissonance reduction to the extent that dissonance is likely to be reduced via approach motivational processes, such as changing one's attitudes to be more supportive of the recent behavioral commitment.

Changing one's cognitions to bring them in alignment with each other (discrepancy reduction) is one way of reducing the negative emotion of dissonance. This is the method of reducing dissonance most often measured in research. However, this is not the only way persons can deal with the emotive state of dissonance. It is also possible to trivialize the cognitions (Simon et al., 1995). Drinking alcohol after performing a counterattitudinal act has been shown to eliminate attitude change, presumably by reducing the negative emotional state and therefore the motivation to engage in discrepancy reduction (Steele et al., 1981). The action-based model would predict that reducing dissonance by means other than attitude change would be more likely when action was not greatly needed or when the action implications of the cognitions were low.

It is also possible to experience dissonance and not do anything to reduce it. The negative emotion of dissonance provides motivation, but just because an individual is motivated to do something does not necessarily mean that he or she acts on the motivation. He or she might, instead, continue to experience cognitive discrepancy, in which case, the action-based model predicts that negative affect would remain elevated. The action-based model also predicts that if an individual experienced dissonance and did not reduce it, then the effectiveness of his or her behavior would be hampered. These and other ways of dealing with cognitive discrepancies, and with the negative emotion of dissonance, need to be considered in future research.

The action-based model does not make the claim that dissonance reduction in the direction of a decision always occurs. Sometimes a person makes a decision, and the evidence is overwhelming that the wrong decision has been made. This information would arouse dissonance. When a person realizes that he or she has made a mistake, his or her original decision is no longer the cognition most resistant to change. Consider Leon, who took a new job. After beginning the job, Leon might realize that it is completely unsuitable for him. He will likely not be able to reduce the dissonance associated with his decision; in fact, the negative emotion of dissonance will increase. At some point, if dissonant cognitions continue to increase, then he may reverse his decision and look for a different job (Festinger, 1957, reports the results of such an experiment). Like the original theory of dissonance, the action-based model predicts that the direction of attitude change will be in the direction of the cognition that is most resistant to change.

The action-based model assumes that dissonance processes operate because they are functional, that is, most often useful for the organism. However, the action-based model does not claim that dissonance reduction is always functional. We think of dissonance processes as being similar to other functional, motivated behaviors such as eating. Eating is necessary for the survival of the organism; however, disordered eating can be harmful by leading to obesity and associated health risks. Similarly, if a person makes a poor decision and then reduces the dissonance associated with the decision, then he or she will persist in acting on the decision. The action-based model proposes that dissonance reduction, although not always functional, is functional more often than not. In the majority of cases, it is advantageous for persons to reduce dissonance and act effectively on their decisions. The dissonance-reduction mechanism down-regulates continued psychological conflict that would interfere with effective action.

Comparison to Other Theories Concerned With Dissonance Processes

Self-consistency and self-affirmation models have each proposed different underlying motivations for dissonance reduction. According to the self-consistency model, individuals experience dissonance when they perceive themselves as behaving immorally, incompetently, or irrationally (Aronson, 1969, 1999). The self-affirmation model (Steele, 1988) posits that "dissonance is not fundamentally the distress of psychological inconsistency, or more particularly the distress of self-inconsistency, but the distress of a threatened sense of self-integrity" (Steele et al., 1993, p. 893). One of the primary predictions of these self-models is that self-esteem should moderate discrepancy reduction, but the two models make opposite predictions. That is, the self-consistency model predicts that high self-esteem individuals should show more evidence of dissonance because the degree of inconsistency should be greater for high- than low self-esteem persons. In contrast, the self-affirmation model predicts that low self-esteem individuals should show more evidence of dissonance (i.e., attitude change) because they possess fewer resources with which to deal with the dissonance. Results concerning these predictions are mixed. Most recent research on these models has found that self-esteem does not moderate dissonance reduction unless the self is primed in near temporal proximity to the dissonance-inducing situation (Steele et al., 1993; Stone & Cooper, 2003).

In addition, self-models of dissonance have difficulty explaining the dissonance effects produced in rats (Lawrence & Festinger, 1962), which are believed to lack self-conceptions of morality, rationality, and competence. On the basis of the past research, it is probably most accurate to suggest that the self-models provide variables that may affect the magnitude and/or direction of discrepancy reduction (e.g., attitude change), but these self-models do not provide explanations of the basic dissonance motivation.

We suggest that the action-based model provides an explanation of the underlying, basic motivation behind dissonance processes. The action-based model assumes that, in most cases, dissonance processes are behaviorally adaptive. Dissonance reduction primarily functions to facilitate effective action. The reason organisms experience discomfort when they hold conflicting cognitions is because conflicting cognitions impede effective action. More important, the action-based model generated the present predictions, whereas the self versions of dissonance would not have generated such predictions.

Notwithstanding the above-mentioned theoretical differences, one may question whether the manipulation of relative left frontal cortical activity (Experiment 1) or the manipulation of action orientation (Experiment 2) affected self-esteem, and this change in self-esteem caused the change in spreading of alternatives. First, for this explanation to be plausible, one would have to argue that the relative left frontal deactivation and action orientation affected self-esteem. However, there are no previous data to support such a claim. In addition, in Experiment 2, negative affect did not differ between conditions, and the action-orientation and positive-nonaction condition showed equivalent increases in positive affect. These results, therefore, do not support an alternative interpretation on the basis of self-esteem because positive and negative affect measures are affected by self-esteem manipulations. Additional one-way ANOVAs on the two items most similar to items on self-esteem scales ("feel good about myself"; "displeased with myself") revealed no significant effects of condition ($ps > .20$).

Summary and Conclusion

By connecting over 50 years of behavioral research on cognitive dissonance processes with more recent neuroscience theory and research on the motivational functions of asymmetrical frontal cortical activity, the present research supports a recently developed conceptual understanding of dissonance reduction processes. Rather than focusing on irrational defenses of the ego, the action-based model suggests that dissonance processes are motivational processes that assist in the implementation of intentions and commitments and may ultimately assist in facilitating effective behavior. It is hoped that this new way of thinking about dissonance processes will stimulate research on dissonance theory and assist in connecting the large body of dissonance theory evidence with other research literatures concerned with action orientation, behavioral regulation, emotion regulation, and the neural processes that underlie these important psychological processes.

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Received September 10, 2006
Revision received July 5, 2007
Accepted July 6, 2007 ■