”Neural activity predicts attitude change in cognitive dissonance”

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Item	**Target sentences**	**Dissonance Mean (SD)**	**Control Mean (SD)**
1.	The scanner makes me dizzy	7.38 (2.10)	7.51 (1.83)
2.	The loud noise of the scanner is too obnoxious	5.40 (2.56)	5.04 (2.56)
3.	The scanner is uncomfortably small and narrow	6.58 (2.48)	4.84 (2.49)
4.	It's too cold in the scanner	6.80 (2.10)	5.26 (2.85)
5.	The scanner makes my back hurt	6.35 (2.66)	5.70 (2.70)
6.	I want to get out of here as soon as possible	5.70 (2.23)	4.03 (2.55)
7.	The task is very boring	4.95 (2.01)	4.06 (1.99)
8.	The task makes me really tired	4.44 (2.34)	3.85 (2.50)
9.	It's disorienting being alone in the scanner room	7.86 (1.23)	6.61 (2.53)
10.	I feel claustrophobic in the scanner	8.13 (0.96)	6.99 (1.96)
11.	The scanner is uncomfortable, because I cannot move	5.93 (2.21)	3.05 (2.80)
12.	The scanner is uncomfortable, because I need a restroom break	6.74 (2.57)	6.17 (3.01)
13.	I have no problem with these button boxes	7.15 (2.34)	5.88 (3.08)
14.	The scanner feels very comfortable	4.98 (2.06)	3.42 (2.40)
15.	I feel calm, peaceful in the scanner	6.67 (1.97)	3.85 (2.07)
16.	The rhythmic clicking of the scanner is relaxing	4.88 (2.78)	3.95 (2.45)
17.	It's nice to get attention from the experimenters	6.00 (1.88)	5.41 (1.76)
18.	The task is interesting	5.00 (2.17)	4.05 (2.18)
19.	The task is engaging	4.89 (1.74)	4. 85 (1.93)
20.	I feel secure and safe in the scanner	6.71 (1.51)	5.35 (2.40)
21.	The scanner environment is very pleasant	5.55 (1.86)	3.78 (2.08)
22.	I like being in the scanner	4.91 (2.19)	3.18 (1.96)
23.	I quickly got used to the scanner	7.28 (1.87)	6.70 (2.40)
24.	The temperature is nice in the scanner	6.27 (2.43)	5.22 (2.55)
25.	The "helmet" around my head makes me feel secure	6.05 (1.60)	4.06 (2.33)
Average		**6.10 (.95)**	**5.50 (1.25)**

Supplementary Table 1. Target sentences. With average final ratings for the dissonance and control groups, collected at the end outside of the scanner. For positively phrased items (31 – 25), this was measured from the left end of the line; for negatively phrased items (1 – 12), this was measured from the right (in cm; *SD* in parentheses). Thus, higher item scores reflect greater task/scanner enjoyment. The average composite score is listed in the bottom row.

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Item	Neutral sentences
1.	The weather is very bad today
2.	I don't like going to clubs
3.	I like to take a shower every day
4.	I hate having financial troubles
5.	I like to dine out frequently
6.	I hate cleaning my place
7.	I enjoy doing the dishes
8.	I am very much a morning person
9.	I like to keep up with the news and current events
10.	I rarely read fiction
11.	I hate the music they make these days
12.	It is very pleasant living in this area
13.	There's just nothing fun to do in this area
14.	I love watching sports on T.V.
15.	I do not exercise nearly enough
16.	Generally, I care about what other people think of me
17.	I love to eat macaroni and cheese
18.	I strongly dislike being around people who smoke
19.	I like animals and I have a pet
20.	I don't like wearing clothes that make me stand out
21.	I like to dress in black a lot
22.	It is spooky walking through the streets at night
23.	I like to stay inside all the time
24.	I know some people who are very obnoxious
25.	I dislike watching sitcoms, they are never very funny
26.	I am currently lying down
27.	I am currently sitting up
28.	I am lying in a tube
29	I am in an open space
30.	I am participating in a research study
31.	I am a patient in this hospital
32.	I removed some clothes and jewelry before getting in here
33.	I did not remove anything before getting in the scanner
34.	The scanner is making sounds right now
35.	The scanner is not making any sounds right now
36.	I am wearing jeans
37.	Right now I am wearing my shoes
38.	I can get out of the scanner whenever I want

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39.	I have one or more tattoos on my body
40.	My feet are touching each other right now
41.	My hands are touching each other right now
42.	My front teeth are touching each other right now
43.	My tongue is touching my front teeth
44.	I am wearing glasses or contacts
45.	I am wearing a tight belt
46.	I am unable to smell my own cologne right now
47.	My mouth is dry right now
48.	I can feel my shoes right now
49.	I feel hungry right now
50.	I am not wearing any socks right now

Supplementary Table 2. Neutral sentences. Items 1 – 25 are general attitude statements about topics unrelated to the scanner; items 26 – 50 are objective statements about the participant's current physical situation in the scanner.

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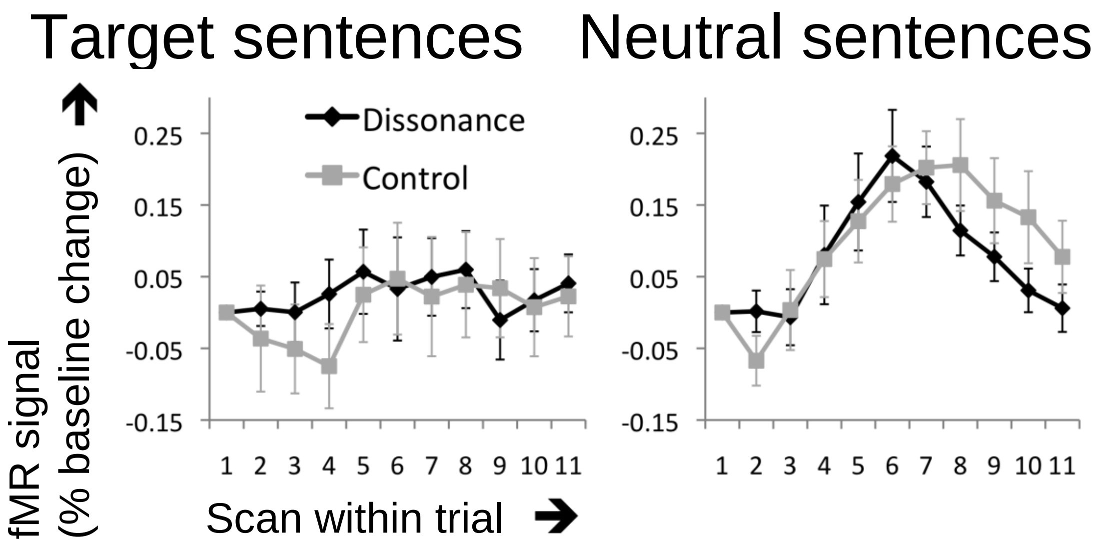

Supplementary Figure 1: Activation of the rostral medial prefrontal cortex (Talairach *x, y*, *z* = –6, 53, 6). This region is often observed to be involved with person perception, mentalizing, and the processing of self-referential information. However, this region did not show a significant sentence type by experimental group interaction, any between group differences for either the target or neutral sentences, nor any significant correlations with final attitude scores. Error bars, ± s.e.m.

Supplementary Methods

First "boring" task. After providing consent, participants were shown the MR facility and control room. They were informed that what they would see on screen while in the scanner was also visible on a screen in the control room. Prior to entering the scanner, participants were given instructions how to perform the first task, and were told – as in all fMRI experiments – that while in the scanner, they should remain completely still and refrain from any movement.

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Participants first performed a force-choice response task in a standard cognitive neuroimaging experiment. For half of the participants, this was a Simon task, in which participants see red or green squares flashed on the left or right side of the screen and respond with a left or right hand button press to the color, ignoring the location. For the other half, this was a task in which participants saw number stimuli presented in the middle of the screen, and responded with a left or right hand button press to the digit's identity according to an a priori established set of random mappings. In both cases, the task contained blocks of stimuli during which the participant was to emphasize speed over accuracy, and blocks during which s/he was to emphasize accuracy over speed. In both cases, this experiment lasted about 45 minutes.

Supplementary Results

Performance. Reaction times (RTs) to the sentence stimuli in the scanner for the without-pretest dissonance group were 3,348 ms (*SD* = 415) to the neutral sentences and 3,582 ms (*SD* = 723) to the target sentences; for the without-pretest control group, RTs were 3,419 ms (*SD* = 428) to the neutral sentences and 2,787 ms (*SD* = 471) to the target sentences. For the with-pretest dissonance group, RT were 4106 ms (*SD* = 1,155) to the neutral sentences and 3,361 ms (*SD* = 398) to the target sentences; for the with-pretest control group, RTs were 4,605 ms (*SD* = 1273) to the neutral sentences and 2,799 ms (*SD* = 506) to the target sentences.

Analysis of these RTs revealed a significant interaction between sentence type and experimental group, $F_{1, 39} = 29.93$, $P < 0.001$. RTs to the neutral sentences were comparable in the dissonance and control groups, $F_{1, 39} = 0.33$, $P = 0.57$: RTs to the target

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sentences were faster in the control groups than in the dissonance groups, $F_{1, 39} = 16.96$, $P < 0.001$. No main effects or interactions involving pretest presence were found, $F_{1, 39}$ range = 0.004 – 0.85, all $P > 0.3$

In-scanner ratings. To verify whether participants complied with the instructions, we analyzed in-scanner ratings of the target sentences. Responses were coded from 0 to 5; 5 corresponding to "completely disagree" for sentences we expected them to disagree with (i.e., sentence 1 – 12 in Supplementary Table 1) and "completely agree" for sentences we expected them to agree with (i.e., sentence 13 – 25 in Supplementary Table 1). Participants in all groups rated all sentences positively, showing all groups behaved as expected. However, in-scanner ratings for the control groups ($M = 4.7$, $SD = 0.5$, and $M = 4.8$, $SD = 0.2$, for the without- and with-pretest groups, respectively) were slightly more positive than in-scanner ratings for the dissonance groups ($M = 4.1$, $SD = 0.5$, and $M = 4.3$, $SD = 0.3$, for the without- and with-pretest groups, respectively), $F_{1, 39} = 15.54$, $P < 0.001$. This is consistent with the fact that participants in the dissonance groups tended to avoid extreme ratings (completely agree/disagree); during debriefing, several participants indicated they did so because they felt it would be more convincing to the "patient" in the scanner control room, and less obvious that they were lying. No effect of pretest presence or interaction of pretest presence and experimental groups was found, $F_{1, 39}$ range = 0.28 – 0.103, all $P > 0.3$, again suggesting the results were comparable across the two experiments.

Remaining correlations between activation and final attitude. For right PMd, there was a trend towards significance in the dissonance group, $r = 0.41$, $P = 0.090$, and a trend

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towards a negative correlation in the control group, $r = -0.43$, $P = 0.065$; the ANCOVA suggested these to be significantly different, $F_{1, 35} = 7.42$, $P = 0.010$. In the right angular gyrus, there was a negative correlation in the control group, $r = 0.50$, $P = 0.03$, while the dissonance group did not show a significant correlation, $r = 0.22$, $P = 0.38$; these were not significantly different in a subsequent ANCOVA, $F_{1, 35} = 0.43$, $P = 0.52$. ANCOVAs and within-group correlations for either group did not reach significance for any of the other regions, $F_{1, 35}$ range = 0.91 – 2.71, all $P > 0.1$; r range = –0.26 – 0.39, all $P > 0.1$.

Dissonance group analysis. Comparison between the neural response to target and neutral sentences within the dissonance groups (collapsed across with- and without-pretest groups) revealed, apart from two regions in the dACC overlapping with the regions identified previously (Region 1: volume = 1,701 mm^3; *x, y, z* = –1, 29, 32; Region 2: volume = 594 mm^3; *x, y, z* = –3, 14, 28), greater activation to the target than to the control sentences in the right MFG (Brodmann's area 9; Volume = 756 mm^3; *x, y, z* = 21, 44, 31), the posterior cingulate cortex (Brodmann's area 23/31; Volume = 5,427 mm^3; *x, y, z* = 0, –25, 28), and the right precuneus (Brodmann's area 7/31; Volume = 1,539 mm^3; *x, y, z* = 12, –66, 29). Conversely, activation was greater to neutral than to target sentences in the region of the left rostral medial prefrontal cortex (Brodmann's area 10; Volume = 513 mm^3; *x, y, z* = 12, 52, 4).

Post-hoc analyses revealed that the posterior cingulate cortex showed a main effect of sentence type, $F_{1, 41} = 47.27$, $P < 0.0001$, but no significant interaction between sentence type and group, $F_{1, 41} = 2.32$, $P = 0.14$, suggesting this region showed a similarly increased response to the target compared to the neutral sentences in both the dissonance

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and control groups. The right precuneus showed a main effect of sentence type, $F_{1, 41}$ = 36.68, $P < 0.0001$, as well as a significant interaction between sentence type and group, $F_{1, 41}$ = 9.57, P = 0.004; further post-hoc tests showed that activation in this region was significantly greater to target than to neutral sentences in the dissonance group, t_{41} = 2.30, P = 0.027, but not in the control group, t_{41} = –0.32, P = 0.75. Similarly, the right MFG showed both showed a main effect of sentence type, $F_{1, 41}$ = 13.32, P = 0.001, as well as a significant interaction between sentence type and group, $F_{1, 41}$ = 8.99, P = 0.005; however, further post-hoc tests showed that activation in this region did not differ between the two groups to neither the target sentences, t_{41} = 1.57, P = 0.12, nor to neutral sentences, t_{41} = –0.74, P = 0.46. The left rostral medial prefrontal cortex responded more to neutral than to target sentences as indicated by a main effect of sentence type, $F_{1, 41}$ = 8.06, P = 0.007, but did not respond differentially between groups, $F_{1, 41}$ = 0.002, P = 0.97.

In the precuneus, activation was also related to the final attitude scores in the dissonance group, partial r = 0.48, P = 0.046, but not in the control group, partial r = 0.03, P = 0.90; the ANCOVA was marginally significant, $F_{1, 35}$ = 3.21, P = 0.082. No significant correlations were found in posterior cingulate, in either group, partial r range = 0.13 – 0.38, all $P > 0.12$. Interestingly, activation the right MFG region correlated with final attitude scores in the control group, partial r = 0.57, P = 0.011, but not in the dissonance group, partial r = 0.18 P = 0.46, control group r = 0.57, P = 0.011; however, the ANCOVA was not significant, $F_{1, 35}$ = 0.08, P = 0.78, meaning the partial correlations between the groups were not significantly different from one another.

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Different pretest groups analysis. To further test for the robustness of these findings, we repeated the whole-brain experimental group (dissonance, control) by sentence type (target, neutral) ANOVA, using participant as random effect, at $\alpha = 0.001$ (uncorrected), this time taking only the without-pretest groups. A cluster size threshold of 13 voxels corrected for multiple comparisons at $\alpha = 0.01$. This analysis revealed differential activation in both dACC (BA = 24/32, left: Talairach *x, y, z* = –8, 28, 33, Vol. = 756 $mm^{3;}$; right: Talairach *x, y, z* = 11, 25, 35, Vol. = 756 mm^3), and right anterior insula (Talairach *x, y, z* = 31, 19, 13, Vol. = 405 mm^3). Post-hoc *t*-tests performed verified that activation to control sentences did not differ significantly between the dissonance and control groups, t_{22} range = 0.84 – 1.12, all $P > 0.1$; activation to the target sentences for these regions was greater in the dissonance group than in the control group, t_{22} range = 2.20 – 3.06, all $P < 0.05$. Controlling for RT, activation in these regions significantly predicted final attitude scores in the dissonance group, partial *r* range = 0.75 – 0.86, all $P < 0.05$, but not in the control group, partial *r* range = –0.05 – –0.08, all $P > 0.8$. ANCOVAs showed these correlations to be significantly higher in the dissonance group than in the control group, $F_{1, 18}$ range = 5.43 – 13.11, all $P < 0.05$. Next we took the regions from this analysis as regions of interest in an analysis of the with-pretest groups. We again correlated the peak of the BOLD signal with final attitude score, now correcting for both pretest score and RT. In the dACC, this partial correlation was significant in the dissonance group, partial $r = 0.76$, $P = 0.030$, but not in the control group, partial $r = 0.09$, $P = 0.84$; an ANCOVA revealed a trend towards this correlation being greater in the dissonance than in the control group, $F_{1, 13} = 4.14$, $P = 0.063$. When, instead of using pretest as a covariate, we used the difference between *z*-scored pretests

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and final attitude scores, dACC signal significantly predicted attitude change, as indexed by this difference measure, in the dissonance group (correcting for RT), partial $r = 0.88$, $P = 0.002$, but not in the control group, partial $r = 0.02$, $P = 0.96$; an ANCOVA verified that this correlation was significantly greater in the dissonance than in the control group, $F_{1, 14} = 9.00$, $P = 0.010$. However, no significant effects were found for the right anterior insula (all $P > 0.2$), suggesting dACC activation is more closely tied to dissonance-induced attitude change than is the right anterior insula.

Reanalysis with excluded participants. As mentioned, participants in the dissonance group who confessed to having doubts about the cover story, or did not believe it at all, were rejected from the analysis. This raises the potential concern that the selection of participants in the dissonance group, compared to the control group, was not random; the selection criterion could have introduced systematic subject differences in the behavioral and/or fMRI results. For example, the included participants might have been less critical, or have other cognitive or personality characteristics that could have influenced the behavioral or fMRI data, biasing the results. To exclude this possibility, we re-analyzed data from the without-pretest groups, with the nonbelievers included. One of these participants had to be excluded for excessive movement, leaving 7. Thus, the total number of participants in the dissonance group for these reanalyses was 18.

The mean final attitude score for the nonbelievers was 5.92 ($SD = 2.03$), in between the scores of the control group and the dissonance group with the nonbelievers excluded. When these participants were included with the dissonance group, the dissonance group's final attitude scores were still significantly greater than the control group's scores, t_{29} =

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2.10, $P = 0.044$. Similarly, all three regions identified by the experimental group by sentence type interaction continued to show significant experimental group by sentence type interactions, all $F_{1, 29} > 9.51$, all $P < 0.005$. For both dACC regions and the right anterior insula, activation to the neutral sentences did not differ significantly between the two groups, t_{29} range = 0.90 – 1.18, all $P > 0.37$, while target sentences elicited greater activity in the dissonance group than in the control group, t_{29} range = 2.13 – 2.71, all $P < 0.05$. Thus, it is unlikely that the selection criterion introduced any bias in the results.

It should be kept in mind, however, that the results of these reanalyses are difficult to interpret, considering the absence of any theoretical framework to interpret these results. Some of the excluded participants confessed to believe the cover story halfway; others claimed not to believe it from the start. They might have been amused or annoyed by the cover story; we did not test the effects of their disbelief on their feelings or responses, as these possibilities were beyond the scope of our study.

Rostral medial prefrontal cortex. To investigate a possible role for the rostral medial prefrontal cortex in cognitive dissonance (see Supplementary Discussion), we took the peak voxel of activation from a recent study[51] that found modulation of this region by self-relevance (Talairach $x, y, z = –6, 53, 6$). Extracted time courses for this region are displayed in Supplementary Figure 1.

As before, we tested for possible differences in activation on the per-participant, per-sentence peak activation. A repeated measures sentence type by experimental group ANOVA revealed a significant main effect of sentence type, $F_{1, 41} = 7.04$, $P = 0.011$, showing neutral sentences to elicit more activity in this region than target sentences in

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both groups, but we observed no significant interaction, $F_{1, 41} = 0.18$, $P = 0.67$, suggesting that this region's activation was not modulated by dissonance.

Supplementary Discussion

Induced compliance. We reasoned that responding to sentences on a Likert scale with others observing would be equivalent to making an actual argument. Thus, we believe that the basic design of our study is similar to the classic induced compliance paradigm[2]. We predicted that dissonance would be more aroused in the dissonance group than in the control group, by several manipulations. First, participants in the dissonance group were not paid to make the argument (or were not aware that they were). It is usually found in the induced compliance paradigm that participants who receive less reward shift their attitudes more[2]. The lack of incentive or reward increases dissonance; the smaller the reward to engage in the counter-attitudinal behavior, the greater the attitude change. Second, in our experiment, participants could freely decide whether or not to comply with task instructions. This is consistent with the finding that when participants do not perceive any freedom to engage in the counter-attitudinal argument, there is no attitude change, and probably little dissonance. The feeling that one freely engaged in the counter-attitudinal behavior increases dissonance, while explicit coercion reduces it[3, 5-7, 9]. Third, it has often been found that the effects of cognitive dissonance in induced compliance paradigms tend to be greater when the counter-attitudinal argument is perceived to have some real-world impact[3, 9, 12]. When participants are able to trivialize their behavior, it causes less dissonance. This manipulation was included in our

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experiment by having the participants in the dissonance group believe that their (counter-attitudinal) argument would convince a nervous patient to be scanned.

Self-referential processing and mentalizing. Since Festinger proposed the original dissonance theory[1, 2], there have been several attempts to revise the original theory. Many of these revisions have emphasized a role for the self in cognitive dissonance and its reduction. For instance, self-consistency theory posits that dissonance reduction serves to reduce the conflict between the behavior and the self-concept of a competent, moral, rational individual[52]. Self-reaffirmation theory holds that dissonance reduction serves to restore a threatened self-image[53]. The "new look" theory proposed that dissonance reduction effects are the results of participants feeling personally responsible for producing aversive consequences[12]. Most radically, self-perception theory has proposed that people's attitude shifts are simply the result of self-observation[33]. However, recent years have challenged each of these perspectives[3, 5, 37, 54], and have seen a return to the original version of the theory[1], with cognition about the self as a modulating factor[55].

Self-referential processing has frequently been associated with activation of the rostral medial prefrontal cortex[51]. To investigate whether it could play a role in cognitive dissonance, we selected a region from a recent study[56] (Talairach x, y, z = –6, 53, 6). However, in both experimental groups, activation was greater to the control than to the target sentences; activation to the target sentences did not differ depending on group. An obvious explanation for this might be that giving one's honest attitude involves more self-processing than responding to a context-dependent response rule. However, these

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results do suggest that there was no differential role for self-processing in the present study to explain our results, at least at reflected by rostral medial prefrontal activation.

Relatedly, it could be argued that in our experiment, the counter-attitudinal behavior in the dissonance group represents a more “social” or “public” condition than the performance by the participants in the control group, and that this might represent a potential confound for the interpretation of our neuroimaging data. However, while person perception and attributing mental states to others have indeed been linked to the medial frontal lobe, activation related to these functions is typically observed in the rostral medial prefrontal cortex rather than the dACC[57]. As outlined above, this region was not differentially activated between the two groups. Instead, dACC engaged by cognitive dissonance in our study has frequently been linked to cognitive conflict. Thus, it is highly unlikely that this difference between the two groups represents a confound.

Future directions. It is important to note that our study concerns the representation of cognitive dissonance; it did not address the resolution of cognitive dissonance, which presumably takes place prior to or during the final attitude measure. Indeed, the conflict theory of the dACC holds that this region is involved in detecting and representing conflict but not the actual conflict reduction; thus, the conflict monitoring theory predicts that the dACC represents the dissonance but is not directly involved in reducing the dissonance. Future neuroimaging studies might focus on the time intervals between the counter-attitudinal behavior and the final attitude measure, or the final attitude measure itself. Psychophysiogical research has suggested that the reduction of cognitive dissonance is associated with a reduction in left frontal alpha in the EEG[57], suggesting

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that dissonance reduction is carried out by the control functions of the left lateral prefrontal cortex. Thus, verifying this prediction would be an important topic for future neuroimaging studies of cognitive dissonance.

In our discussion, we have focused on the conflict detection theory of dACC functioning. However, other theories of dACC functioning have been proposed. For instance, it has been proposed that rather than responding to conflict, it responds to error likelihood[57]. More recently, it has been suggested that the dACC plays a role in reward-based learning[58] or reward-based response selection[59]. We do not know to what degree these alternative theories are compatible with the present results, and future research will be needed to address these issues. However, considering the conceptual similarity between dissonance and conflict, we believe that the conflict theory provides a particularly parsimonious interpretation of our results.

In the classical induced compliance paradigm, participants are asked to make a counter-attitudinal argument. In our paradigm, we had participants rate sentences; they had to lie to the target sentences, pretending the scanner environment was pleasant and comfortable and that the task was engaging. Our assumption was that responding in this way to the target sentences was similar to counter-attitudinal behavior in the traditional induced compliance paradigm. Although attitude change did occur, one might reasonably question the validity of the paradigm, or whether the basic processes involved may have been inadvertently altered by this change. Although this seems unlikely and not parsimonious to us, and this criticism can be extended to any neuroimaging adaptation of

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a social psychology paradigm, future research might address whether our task does indeed constitute counter-attitudinal behavior.

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