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Deciphering spousal intentions: An fMRI study of couple communication

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ABSTRACT

Several relational theories suggest that advice, particularly advice in areas important to the self, may be cognitively processed differently than other types of support (e.g., non-directive support) or low importance advice. Little is known, however, about the neurocognitive substrates of such complex social behaviors. We hypothesized that the Superior Temporal Sulcus (STS) and the Medial Prefrontal Cortex (MPFC), cortical regions previously linked to Theory of Mind (ToM), would be more active for high than low importance advice. Results indicated that high importance advice was associated with greater activation in the left MPFC and bilaterally in the STS. Similar results were obtained when compared to positive comments. These findings indicate that when given advice individuals may be attempting to infer motivation.

KEY WORDS: advice • fMRI • functional magnetic resonance imaging • marriage • medial prefrontal cortex • MPFC • social neuroscience • social support • STS • superior temporal sulcus • theory of mind • ToM

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The support we receive from friends and family exerts a powerful influence on our mental as well as physical health across the life-span. The impact of social support is sufficiently robust that individuals who are deprived of support are at risk for serious health complications including heart disease, cancer, and premature death (Wills, 1990). In particular, the support provided by one's spouse, or others with a close, confiding relationship, appears to be uniquely beneficial (Brown & Harris, 1978; Julien & Markman, 1991). Despite the importance of social support provided by intimate partners, several gaps remain regarding the understanding of this critical process (Cutrona & Suhr, 1994; Reis, 1990). For example, within intimate relationships directive support, i.e., problem solving or advice, was found to be the most common form of support (Beach & Gupta, 2006; Carels & Baucom, 1999; Cutrona, 1996). However, several other reports suggest advice may be a less than optimal strategy for many situations (Cutrona, 1996). Julien and colleagues (1994) observed that directive support was likely to be interpreted as annoying rather than helpful or comforting and may be related to depression (Beach & Gupta, 2006). Other evidence suggests that directive support may be viewed as helpful, but only under certain circumstances, i.e., when advice is desired (Cutrona, 1990). Data from our lab suggest that advice is processed differently than non-directive support. In particular it may be increasingly difficult to receive the potential benefits of advice as the topic area becomes more personally salient (i.e., more related to a person's area of self-definition, or personal expertise) (Gunther, Beach, Miller, & Yanasak, 2006). Questions remain however as to why directive advice is processed differently, and why the nature of this difference appears to be yoked to level of personal importance. It is also unclear what type of mental process or computation could account for the cognitive complexity of directive advice.

Social psychological models of response to performance feedback (e.g., Tesser, Millar, & Moore, 1988; Thoits, 1992; Wills & Resko, 2004) suggest the possibility that, under some circumstances, individuals may interpret advice as a form of self-evaluation threat. That is, in response to advice, partners could wonder "What is my partner trying to tell me? That I'm bad at ______?" Such reactions, and the ensuing attempt to decipher the others' intentions, have been termed "Theory of Mind," or ToM (Premack & Woodruff, 1978). Consistent with ToM, we hypothesized that advice, particularly when directed at a personally relevant domain of expertise, would cause individuals to become more vigilant about the intentions of the advice giver.

We used functional magnetic resonance imaging (fMRI) with the aim of elucidating the nature of the cognitive processes underlying potential receptivity to directive support from one's spouse. Like traditional MRI, functional MRI uses the intrinsic magnetic properties of a substance to produce images of internal anatomical structures such as the brain. Functional MRI differs in that increases in neural activity cause changes in the MR signal. Increased neuronal activity causes a greater demand for oxygen. The vascular system then increases the supply of oxygenated hemoglobin relative to deoxygenated hemoglobin. Since deoxygenated hemoglobin attenuates the MR signal, the vascular response therefore leads to a measurable change in the MR signal that is believed to be related to neuronal activity (Huettel, 2004; Rinck, 2006). This mechanism is known as the BOLD (blood-oxygen-level dependent) effect and is usually referred to as T2*. By taking a rapid series of *functional* images, it is possible to infer which regions of the brain are more active during certain tasks. Functional images show changes in signal intensity (brightness) depending on the level of oxygen in the blood. Using this image property, dynamic changes in brain activity can be inferred by signal intensity changes that occur during different cognitive states in different regions of the brain. When neurons become more active, blood flow is increased to that area of the brain. More specifically, new oxygenated hemoglobin (oxygen rich blood) flows into the local cerebral capillary bed where neuronal activity has increased. Conversely, the deoxygenated hemoglobin (oxygen depleted blood) is washed out of this region and returned to circulation. In the MR scanner, oxygenated hemoglobin *increases* the T2* signal intensity. Broadly speaking, it is this relative increase in signal intensity by the ratio of oxygenated to deoxygenated hemoglobin that is believed to be a proxy for neuronal activation. The functional images are then superimposed on anatomical pictures of the brain and analyzed statistically to determine which brain regions were significantly more or less active during the various cognitive states.

Several recent cognitive neuroscience studies have examined the brain's involvement in interpersonal processes (e.g., Aron et al., 2005; Aron & Van Lange, 2006; Bartels & Zeki, 2000; Bartels & Zeki, 2004; Coan, Schaefer, & Davidson, 2006; Gillath, Bunge, Shaver, Wendelken, & Mikulincer, 2005; Ortigue, Bianchi-Demicheli, de C. Hamilton, & Grafton, 2007). In the current study, to the extent that advice prompts one to think more about the advice giver's intentions, we can predict that certain neurocognitive systems will be recruited. A number of studies examining the correlates of ToM have documented the role the superior temporal sulcus (Pelphrey, Morris, & McCarthy, 2004; Winston, Strange, O'Doherty, & Dolan, 2002) as well as the medial prefrontal cortex (Ochsner, Knierim et al., 2004; Walter et al., 2004). Each of these structures is thought to serve specific functions related to social cognition. The superior temporal sulcus (STS) comprises the cortical region of the superior portion of the temporal lobe which descends into the encephelated fold between the temporal lobe and the inferior portion of the parietal cortex. Using single unit recording, early studies in non-human primates provided the first evidence for the STS's role in social cognition. Perrett et al. (1985) found that cells in the STS responded differentially to viewing faces and gaze direction. More recently, converging evidence suggests that the STS is an essential component for social processing. For example, numerous studies have reported STS abnormalities in individuals with autism (for review see Zilbovicius et al., 2006). In normal populations, functional neuroimaging experiments have shown greater activation in the STS when viewing social versus non-social movements of geometrics shapes (Castelli, Frith, Happe, & Frith, 2002), making explicit trustworthiness judgments (Winston et al., 2002), and when attempting to read the minds (take the perspective) of cartoon characters (Gallagher et al., 2000; Pelphrey et al., 2004).

The medial prefrontal cortex (MPFC) has also been consistently associated with ToM tasks. Ruby and Decety (2004) observed activation in the MPFC when participants were asked to take the perspective of others (3rd person) compared to answering questions about a similar scenario from their own perspective (1st person). Ochsner, Knierim et al. (2004) reported parallel findings in an experiment examining perspective taking for emotional scenarios. Walter and colleagues (2004) conducted a fine-grained analysis aimed at differentiating the specific function of the MPFC for social interactions. They concluded that this region is not only attuned to mentalizing about the states of others, but rather, it is specifically involved in assessing the intentions of interaction partners. Based on these prior findings we hypothesized that the STS and the MPFC, cortical regions previously linked to ToM, would be more active for high than low importance advice. We also conducted an exploratory analysis to examine which areas of the brain were broadly more associated with advice compared to positive comments.

Method

Participants

Using random digit dialing, a university survey research center recruited eight couples from the vicinity of a large Southern University. The couples had been married for between one and four years (mean = 2.3; *SD* = 1.1) and husbands and wives both had a mean age of 28.5 years (range = 26–34 and 28–33 respectively). All of the husbands were right-handed and had neither a history of traumatic brain injury nor any conditions which would prohibit their participation in an fMRI experiment (e.g., pace makers). The husbands had a mean of 15.3 years of education (range = 13–18). Written informed consent was obtained from all participants after reading a detailed description of the study approved by the University's Human Participants Institutional Review Board. Couples were paid $150 for their participation.

Stimuli

All participants were told that they would be taking part in a study which would examine brain response to advice in marriage. The experimenters then conducted separate interviews with each partner in order to generate the advice statements presented in the scanner. Investigators operationalized the difference between high and low importance areas by how "expert" the husband rated himself for each domain. Accordingly, high importance domains were defined as those areas in which the husband rated his expertise as higher than his wife's. Experimenters only used a domain if the husband's ratings were 2 standard deviations or greater than his wife's ratings (see Table 1). Using expertise as a proxy for personal importance has frequently been employed as a means of assessing subjective importance (Beach & Tesser, 1993; Beach, Tesser et al., 1996; O'Mahen, Beach, & Tesser, 2000) and is broadly considered to be a psychologically meaningful assessment of importance (Beach, Whitaker, Jones, & Tesser, 2001). Husbands were then asked to "describe a current or potential problem within each of the high and low importance areas. For example, what is a problem that you might have with ______?" Accordingly, each problem was associated with either a high or low importance domain for the husband. During the wives' interviews they were asked to generate directive advice statements in order to "help your husband solve each of the problems they listed." Wives were encouraged to use a statement format such as the following: "One thing you could do to deal with the recent problem you've been having with ______ is to try and ______." Positive comments were generated in a similar manner by asking wives to describe their husbands' positive qualities. They were then asked to write statements expressing these positive sentiments. The experimenter worked with the wives to create sentences that were uniform in length and form, yet applicable to their marriage, ensuring consistency in tone, absence of criticism, and use of pronouns as well as overall form for the statements across spouses.

TABLE 1
Mean (and standard deviation) ratings of advice problem area characteristics

Advice rating	High importance	Low importance	*t*	Sig
Expertise	8.98 (1.80)	2.21 (3.31)	7.28	>.001
Urgency	6.67 (1.51)	6.52 (1.23)	0.42	.68
Affective impact	5.78 (1.93)	5.75 (1.98)	0.05	.96
Controllability	4.17 (1.54)	3.44 (1.57)	1.22	.25
Likelihood	7.42 (1.57)	7.33 (1.21)	0.40	.70

Prior to the scanning session, husbands were also asked to rate each problem for subjective affective impact, urgency, controllability, and likelihood using a Likert scale from 1–10. Results indicated no statistically significant differences between high and low importance area advice statements (see Table 2). Each statement was digitally recorded to be presented in the scanner as the husband listened (see Table 3). Finally, participants were also administered the Beck Depression Inventory (BDI; Beck, Ward, Mendelson, Mock, & Erbaugh, 1961). The BDI is a well studied 21 item instrument that was used to assess the relationship between husbands' level of self-reported depressive symptomology and brain activity.

Each participant also took part in a mock MRI session in order to familiarize themselves with the experimental task and habituate to the scanning environment. While in the scanner husbands were asked to rate the helpfulness of each advice statement on a scale from 1–5 using a hand pad. The wife's statements were presented through headphones using E-Prime

TABLE 2
Linguistic inquiry word count (LIWC) characteristics for wife's statements

Advice rating/LIWC code	Mean HI	Mean LI	Mean POS	*F*
Total words with cognitive explanations/ Cognitive mechanism	3	3.78	*1.75	25.1
Words expressing descriptions/Discrepancy	1.66	2.05	*0.19	42.2
Words with affective significance/Affect	0.75	0.79	*2.84	33.6
Personal pronouns/Pronoun	3.11	3.23	*5.52	31.1

Note. HI = High importance advice statements; LI = Low importance advice statements; POS = Positive comments.

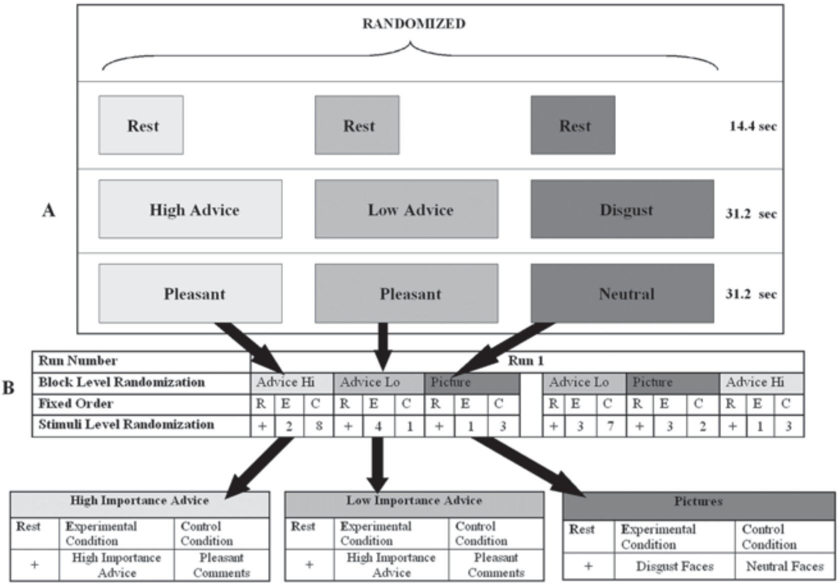
TABLE 3
Examples of high and low importance advice and positive comments

	Domain	Problem	Wife's advice statement
High importance	Finances	Saving enough money	"If you would like to build a savings with what we earn, one thing we could try is taking an agreed upon amount such as fifty dollars out one check a month and put it immediately into savings."
Low importance	Remembering family events	Forgetting an important date	"For remembering birthdays or anniversaries, since you are technologically inclined, you should use a computer type program to remind you regularly about these dates."
Positive comments	Communication	Story telling	"I love the way you sometimes put a dramatic undertone to stories you tell me or situations you're recounting."

software (Schneider, Eschumann, & Zuccolotto, 2002) and the Integrated Functional Imaging System hardware configurations with a custom-prepared dental bite bar for head stabilization. While inside the actual MRI, prior to the onset of the advice statements, participants were required to respond to a series of pre-recorded auditory test questions (e.g., "please press the index finger button on your left hand until I say stop", etc.) to assure that statements would be heard over the (very loud) MRI.

The experimental design contained six blocks: (i) rest period (fixation cross), (ii) high importance advice, (iii) low importance advice, (iv) pictures of facial expressions displaying disgust, (v) neutral facial expressions, and (vi) positive comments (see Figure 1 for a depiction of the experimental design). Each block lasted 31.2 seconds with the exception of the rest period (14.4 seconds). Uniform length of block was achieved by looping the wives'

FIGURE 1
Experimental design – Stimulus presentation was achieved via nested randomization



Note. A) The fMRI stimulus presentation computer randomly chose between one of three possibilities without replacement: 1) Advice Block of High Importance 2) Advice Block of Low Importance or 3) A Picture Block. B) Each of these blocks contained a fixed order sequence consisting of 1) Rest [fixation cross] 2) Experimental Stimuli [advice statements or disgust faces] 3) Control Stimuli [positive comments or neutral faces]. Remaining stimuli was the same for all three blocks (a fixation cross). For the picture blocks, the experimental and control stimuli were faces showing disgust and neutral expressions. Note that figure 3B depicts the actual sequence of stimuli presented in one run for a single participant. After the block level stimuli have been selected, sampling begins again. C) Nested *within* each of these fixed order blocks, the various stimuli were randomly selected without replacement. Each of the experimental and control conditions contained four possible stimuli from which to select. Thus, each stimulus was repeated twice during the course of the entire experiment (four runs). Due to the number of possible stimuli and sampling without replacement, stimuli did not repeat until the third and fourth runs. After each stimulus was randomly chosen (e.g., an advice statement) it would not be repeated until all of the remaining 3 possibilities had been exhausted.
R = Rest (fixation cross); E = Experimental condition; C = Control condition; 1, 2, 3, 4, etc. = the stimuli number which was presented, i.e. high importance advice statement 1 versus 2, etc.

advice audio clips. Blocks 4 & 5 are for a separate experiment to be reported elsewhere. Each advice statement was presented twice in randomized order (2 trials per condition). 104 volumes were collected per condition with the exception of positive comment and rest blocks which were 208 and 144 respectively. The total amount of time that each participant spent in the scanner was approximately 35 minutes.

We quantified the wives' statements for linguistic characteristics by using Linguistic Inquiry and Word Count (LIWC) software (Francis & Pennebaker, 1993) to examine potential confounds which could account for processing differences between the high importance, low importance, and positive statement conditions. The LIWC program is designed to quantify language (e.g., words with affective significance, etc.; see Francis and Pennebaker, 1993). Specific LIWC variables are denoted by italics. After calculating word tallies, we conducted a series of ANOVAs to examine potential differences in (i) use of large words (*Six Letters* – words with six letters or more, *Word Count* – total number of words); (ii) inclusion of explanations (*Cognitive Mechanism*, *Causal Explanations*, *Explanations Involving Insight*, *Descriptive Explanations*); (iii) affective words or personal pronouns (*Affect*, *Pronoun*); and (iv) a particular time orientation (*Time*, *Past*, *Present*, *Future*). The results of the ANOVAs revealed differences between high and low importance advice and positive comments in 4 of the 12 examined variables (*Cognitive Mechanism*, *Discrepancy*, *Affect* and *Pronoun*).

Following ANOVAs, we performed post-hoc, Bonferroni-corrected, comparisons to specify differences among conditions. First, analyses revealed no differences between high and low importance advice statements. Therefore, we collapsed the high and low importance statements and examined differences between positive comments and the advice statements. Results indicated that positive comments contained significantly fewer words than advice for the LIWC variables, *Cognitive Mechanism* and *Discrepancy* and significantly more words for LIWC variables *Affect* and *Pronoun* (see Table 2).

Positive comments likely differed linguistically from advice because the goals underlying these statements differ. These differences may influence processing, so characterizing such differences is important. Since positive comments are intended to be pleasant, they contained significantly more affect-laden words (*Affect*), e.g., "I love the way you sometimes put a dramatic undertone to stories you tell me or situations you're recounting." (See, e.g., the positive comments in Table 3c.) This example also illustrates that positive comments were more likely to contain personal pronouns (*Pronoun*). Wives' are likely attempting to emphasize their personal sentiment toward their husband and his positive qualities. Conversely, because positive comments do not involve problem solving, they contained significantly fewer words in the *Cognitive Mechanism* and *Descriptions* categories, thus making them less complex than advice statements. In summary, certain linguistic differences in advice statements when compared to positive comments appear inherent in each utterance type.

Magnetic Resonance Imaging parameters

Whole anatomical and partial-brain functional imaging data were acquired on a 1.5 T whole-body GE Signa LX Horizon (GE Medical Systems, Milwaukee, Wisconsin, USA) magnetic resonance scanner using a quadrature head coil. A 3-D spoiled-gradient recall (SPGR) pulse sequence was used to acquire a T1 weighted image for anatomic reference (parameters: 120 locations per slab; TE = 2.8 ms; TR = 10.8 ms; one interleave; slice thickness = 1.3 mm with no slice gap; FOV = 24×24 cm; flip angle = 20º; matrix size 256×256). A T2*-sensitive gradient recalled echo pulse sequence with a spiral readout (Glover & Lai, 1998) was used to acquire fMRI images (parameters: TE = 40 ms; TR = 2400 ms; flip angle = 77º; reconstructed matrix size = 64 × 64 mm; FOV = 240 mm; voxel size = 3.75 × 3.75 × 5 mm; voxel size after spatial normalization = 2 × 2 × 2 mm). Image slices were acquired with an axial orientation with the fourth most inferior slice prescribed along the AC/PC line (in-plane resolution = 0.94 mm). We collected 104 image volumes for both high and low importance conditions (208 images for positive comments) at the rate of 2.4 seconds per volume. Our parameters allowed the functional acquisition region depicted in Figures 5–8 by black lines.

fMRI data analysis

Images were reoriented, realigned (residual motion < 1 mm in all planes), normalized to a T1 template from the Montreal Neurological Institute (Evans et al., 1994) and smoothed using a 7.5 by 7.5 by 10 mm full-width at half maximum gaussian kernel within the SPM99 software suite (http://www.fil.ion.ucl.ac.uk/spm). Data were spatially smoothed using this kernel due to the non-isotropic functional scan volume (Friston et al., 2000). The data was then high pass filtered using the default 128 second cutoff period in order to correct for signal drift. SPM99 was used to calculate statistical maps showing brain activity for high versus low importance advice comment blocks using the general linear model with no grand mean scaling and SPM's canonical hemodynamic response function.

Group statistical parametric maps were used to calculate t-test statistics at the $p < 0.001$ level (uncorrected for multiple comparisons) in a random effects analysis (Lane, Axelrod, Yun, Holmes, & Schwarz, 1998) (df = 7) with an extent threshold of 8 voxels in order to reduce false positive activations (Xiong, Gao, Lancaster, & Fox, 1995). MNI coordinates were transformed using the mni2tal routine in Matlab (Matthew Brett, http://www.mrc-cbu.cam.ac.uk/Imaging/Common/ mnispace.shtmland) and are given in Talairach stereotactical space (Talairach & Tournoux, 1988). Coordinates for the most significant voxels within active regions are reported along with z-scores in Tables 4–7 and Figures 5–8. Anatomical locations were determined at the random effects level using automated anatomical labeling (Tzourio-Mazoyer et al., 2002) and are displayed on the MNI canonical 152 composite T1 brain (Evans et al., 1994).

The regions of interest (ROIs) included both the left and right MPFC and STS in areas corresponding to Broadman areas 10 and 22 respectively, as 10 mm diameter spheres centered on the Talairach & Tournoux (1988) coordinates of two separate experiments (Pelphrey et al., 2004; Walter et al., 2004) respectively. The STS was defined bilaterally by the coordinates reported by Pelphrey et al. (2004) (Left STS: x = –57, y = –47, z = 11; Right STS: x = 57, y = –47, z = 11). The MPFC was defined bilaterally as the coordinates reported by Walter and colleagues (2004; Left MPFC: x = –5, y = 52, z = 32; Right MPFC: x = 5, y = 52, z = 32). Signal intensity data were extracted compared to baseline (fixation cross) for each voxel within the 10 mm diameter ROI spheres (Worsley et al., 1996). Data was then averaged across the ROI to obtain a percent intensity signal change value for each participant (Brett, Christoff, Cusack, & Lancaster, 2001). This method of localization and analysis is a sensitive technique for detecting neurocognitive activation differences in a particular brain region for which there is a specific a priori hypothesis (Constable et al., 1998).

Time course data were analyzed by synchronizing temporal onsets of advice statements. Data were then extracted for each participant within SPM99 compared to rest. High importance, low importance, and positive comment data were segregated, averaged, and then converted to percent signal intensity change scores for each condition.

Results

Behavioral results

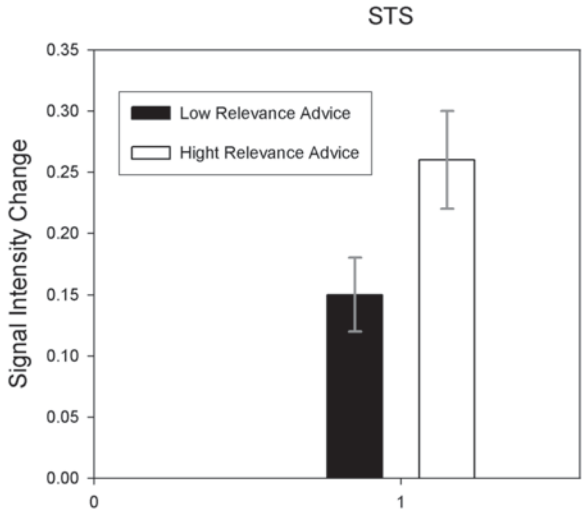
Participant ratings of helpfulness obtained during scanning did not differ between high and low importance advice, $t(7) = 1.03$; $p > .05$. Controversy remains regarding the interpretation of between condition differences in fMRI activations as they relate to differences in behavioral performance. Some investigators view behavioral differences as experimental confounds (Callicott et al., 2003) and believe that lack of significant behavioral differences may facilitate meaningful interpretations of differences in the BOLD response. In this case, activation differences cannot be explained as confounds related to participant's differential responses to the behavioral task. Thus, matched task performance may represent a potential methodological strength. Other researchers, however, view differences in task performance as necessary for interpreting differences in patterns of activation (Wilkinson & Halligan, 2004).

fMRI results

ROIs. We conducted four 2 × 2 ANOVAs on ROI data. The first two ANOVAs examined differences in importance (high importance vs. low importance) by hemisphere (right vs. left) for the STS and MPFC (Constable et al., 1998). The other ANOVAs examined differences in comment type (positive comments vs. advice) by hemisphere (right vs. left) for the caudate and ventral striatum. In the second pair of ANOVAs, high and low importance advice were combined to form a single advice composite variable.

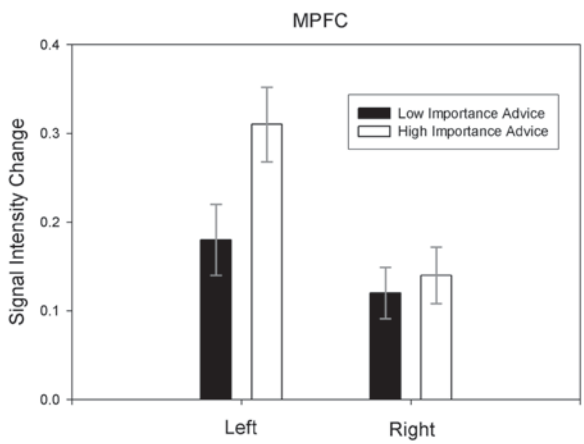
ANOVAs comparing high and low importance statements revealed a hemisphere by importance interaction in the MPFC such that greater activation was observed for high importance advice on the left hemisphere only, $t(7) = 5.04$; $p >. 005$; see Figure 2. In the MPFC, there was a main effect for importance ($F(1, 8) = 10.25$, $p < .03$) where high importance advice was associated with greater activation bi-laterally in the STS; $t(7) = 3.78$; $p < .03$; see Figure 3. Positive comments vs. advice revealed greater activation bi-laterally in the caudate ($t(7) = 3.48$; $p < .05$; see Figure 4), but not the ventral straitum ($t(7) = .95$; $p > .05$).

FIGURE 2
Region of interest (ROI) analysis for signal change bilaterally in the superior temporal sulcus for high and low importance advice compared to baseline (fixation cross)



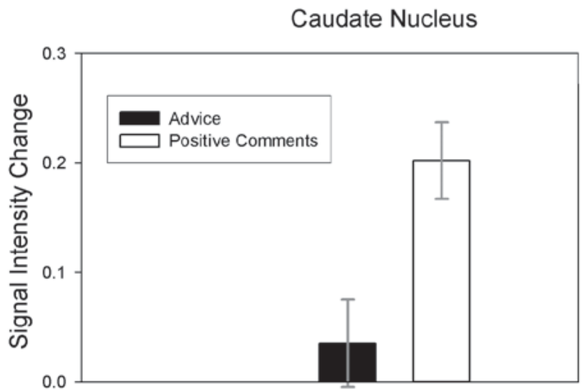
Note. Error bars represent standard deviations. ROIs defined as 10 mm diameter spheres centered on the Talairach coordinates x = +/–57, y = –47, z = 11.

FIGURE 3
Region of interest (ROI) analysis for signal change in the left medial prefrontal cortex for high and low importance advice compared to baseline (fixation cross)



Note. Error bars represent standard deviations. ROI defined as 10 mm diameter sphere centered on the Talairach coordinates x = –5, y = 52, z = 32.

FIGURE 4
Region of interest (ROI) analysis for signal change bilaterally in the caudate nucleus for high and low importance advice compared to positive comments



Note. Error bars represent standard deviations. Talairach coordinates +/–x = 4, y = 0, z = 19.

Group contrasts

High importance advice minus positive comments. Analyses comparing high importance versus positive comments (Table 4 and Figure 5) revealed that high importance produced greater activation in the thalamus (x = –14, y = 4, z = 42; Z = 3.47), the middle and posterior cingulate, extending into the

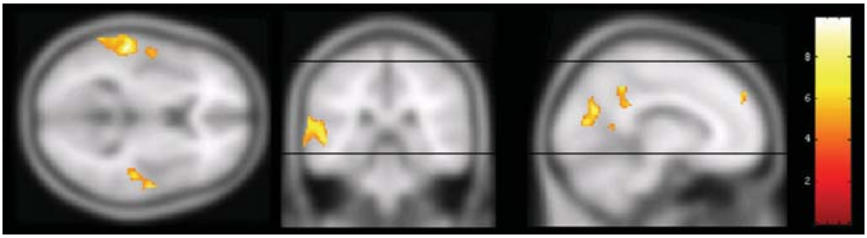
TABLE 4
Brain regions significantly more active when listening to high importance advice than positive comments

Region	Broadman area	L/R	X	Y	Z	Voxels	T score	P value
STS	22	L	–56	–30	6	857	9.90	0.000004
PCC/CU	31	L	–8	–56	24	252	8.68	0.00001
STS	22	R	58	–10	6	242	7.71	0.0001
MPFC	9	L	–12	52	32	50	7.37	0.0001
PCC	31	L	–14	–44	30	151	7.80	0.00003
STS	22	R	58	–22	24	70	8.12	0.0001
STS	22	L	–56	–58	22	170	8.07	0.00001
MTG	21	R	58	–58	4	44	7.76	0.00003
CU	18	R	10	–94	12	18	6.49	0.00003
Thalamus		R	2	–14	4	42	6.31	0.0002
SFG	9	L	–26	48	38	10	5.13	0.0006

Note. Coordinates listed at peak activation for each cluster at 0.001 threshold; Voxels list number of significant voxels in each activation cluster; Voxel size after spatial normalization = 2 × 2 × 2; L = left; R = right; STS = Superior Temporal Sulcus; PCC = Posterior Cingulate Gyrus; CU = Cuneus; MPFC = Medial Prefrontal Cortex; MTG = Middle Temporal Gyrus; SFG = Superior Frontal Gyrus.

FIGURE 5

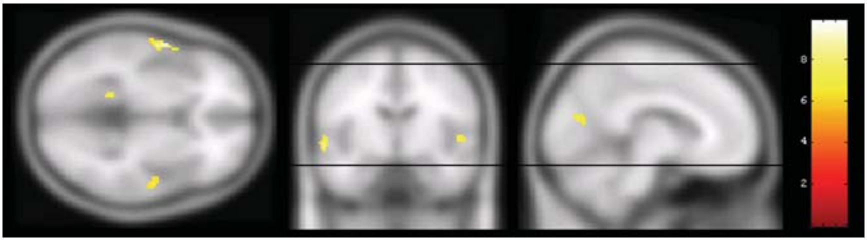
Brain activation map for high importance advice minus positive comments at .001 significance, depicted in neurological orientation at Talairach coordinates z = 6 / y = –30 / x = 0 from left to right respectively



Note. Color bar represents t-statistic.

FIGURE 6

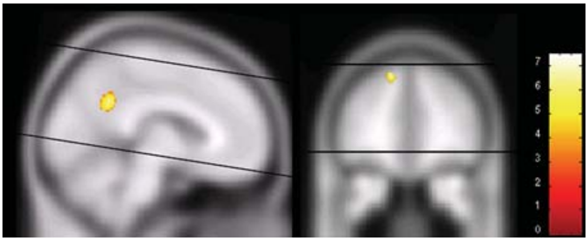
Brain activation map for low importance advice minus positive comments at .001 significance depicted in neurological orientation at Talairach coordinates z = 6 / y = 15 / x = –4 from left to right respectively



Note. Color bar represents t-statistic.

FIGURE 7

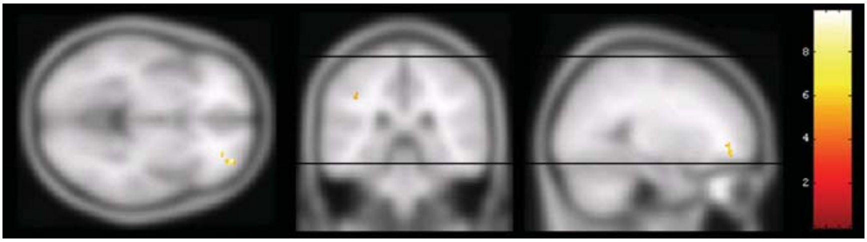
Brain activation map for high importance advice minus low importance advice at .001 significance depicted in neurological orientation at Talairach coordinates z = 32 / y = 42 / x = –2 from left to right respectively



Note. Color bar represents t-statistic.

FIGURE 8

Brain activation map for positive comments minus low importance advice at .001 significance depicted in neurological orientation at Talairach coordinates z = –4 / y = –40 / x = 34 from left to right respectively



Note. Color bar represents t-statistic.

cuneus and posterior parietal cortex (x = –8, y = –56, z = 24; Z = 4.22), the STS and superior temporal sulcus bilaterally (left STS: x = –56, y = –30, z = 6; Z = 4.44; right STS: x = 58, y = –10, z = 6; Z = 4.03) as well as portions of the MPFC (MPFC: x = –12, y = –52, z = 32; Z = 3.98).

Low importance advice minus positive comments. Comparing low importance advice to positive comments revealed a remarkably similar pattern of activations as did the high importance advice versus positive comments analyses. As can be seen in Table 5 and Figure 6, this also included the STS and superior temporal sulcus bilaterally (left STS: x = –58, y = 0, z = 0; Z = 3.94; right STS: x = 34, y = 10, z = 27; Z = 3.90) and the precuneus (x = –16, y = –44, z = 2; Z = 3.47).

TABLE 5
Brain regions significantly more active when listening to low importance advice than positive comments

Region	Broadman area	L/R	X	Y	Z	Voxels	T score	P value
STS	22	L	–58	0	0	141	7.78	0.0001
STS	22	R	34	–32	10	27	7.56	0.0003
Precuneus	31	L	–16	–44	2	20	6.50	0.0005

Note. Coordinates listed at peak activation at 0.001 threshold; Voxels list number of significant voxels in each activation cluster; Voxel size after spatial normalization = 2 × 2 × 2; L = left; R = right; STS = Superior Temporal Sulcus.

Positive comments minus high importance advice. We also conducted the contrast of positive comments minus high importance advice. At the a priori threshold of .001 there were no significant results.

High importance advice minus low importance advice. The high importance minus low importance contrast t-test (see Table 6 and Figure 7) revealed greater response in both the MPFC (x = –12, y = 42, z = 37; Z = 3.81) and the left posterior cingulate cortex (PCC; x = –4, y = –45, z = 32; Z = 3.66).

TABLE 6
Brain regions significantly more active when listening to high importance advice than low importance advice

Region	Broadman area	L/R	X	Y	Z	Voxels	T score	P value
MPFC	9	L	–12	42	37	33	7.16	0.0002
PCC	31	L	–4	–45	32	107	7.01	0.0008

Note. Coordinates listed at peak activation at 0.001 threshold; Peak Activation for Cluster; Voxels list number of significant voxels in each activation cluster; Voxel size after spatial normalization = 2 × 2 × 2; L = left; R = right L = left; R = right; MPFC = Medial Prefrontal Cortex; PCC = Posterior Cingulate Cortex.

The activation depicted in Figure 7 displays a medium size cluster (107 voxels) in the middle portion of the posterior cingulate (x = –4, y = –45, z = 32; Z = 3.66), overlapping slightly with the precuneus. Figure 7 shows a somewhat smaller cluster (48 voxels) overlapping between the border of the dorsal medial prefrontal cortex and the dorsal lateral prefrontal cortex (x = –12, y = 42, z = 37; Z = 3.81).

Positive comments minus low importance advice. The contrast depicting areas that were more active while listening to positive comments than low importance advice revealed small clusters in the right orbital frontal cortex (x = 34, y = 54, z = –4; Z = 4.22) and the inferior parietal cortex (x = –16, y = –40, z = 36; Z = 3.27; See Table 7 & Figure 8). Finally, it is important to note that although the group contrasts did not consistently reveal significant activation that overlapped voxel-by-voxel with the ROIs, overlapping activations from the ROIs were indeed present in the group contrasts when the statistical threshold was lowered (e.g., 0.006).

TABLE 7
Brain regions significantly active when listening to positive comments than low importance advice

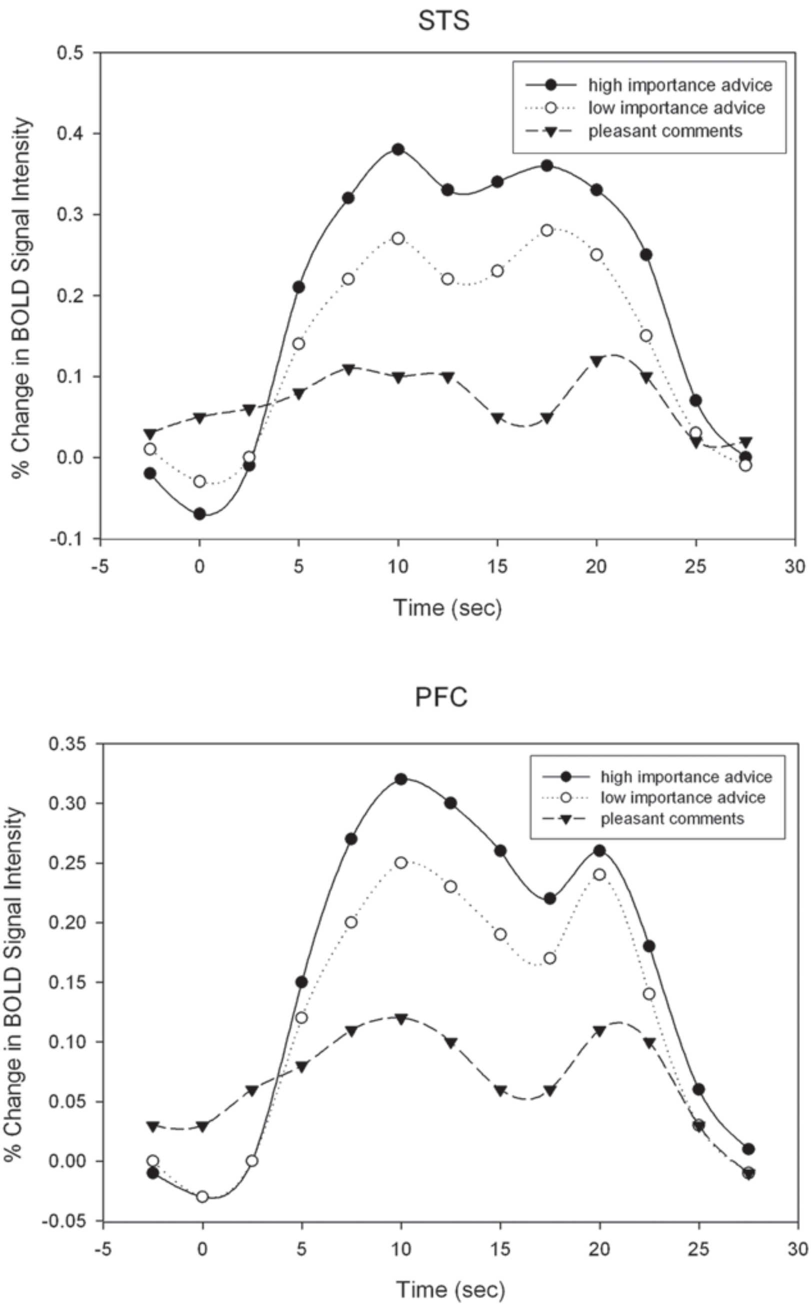
Region	Broadman area	L/R	X	Y	Z	Voxels	T score	P value
OFC	10	R	34	54	–4	19	8.06	0.00001
OFC	10/11	R	30	48	–10	18	6.73	0.0007
IPC	31	L	–16	–40	36	12	6.02	0.0006

Note. Coordinates listed at peak activation at 0.001 threshold; Voxels list number of significant voxels in each activation cluster; Voxel size after spatial normalization = 2 × 2 × 2; L = left; R = right; OFC = Orbital Frontal Cortex; IPC = Inferior Parietal Cortex.

Time course analyses. Time course analyses in the STS and MPFC revealed differences for signal intensities between the three conditions of interest (positive comments, low importance, and high importance advice). Positive comments exhibited the lowest signal, followed by increasing signals for low importance advice and high importance advice respectively (see Figure 9). Responses appeared to peak approximately 10 seconds after stimulus onset and remained elevated for about 13 seconds. There also appeared to be two peaks in the response, perhaps due to the onset of the second loop of the advice statements.

Correlational analyses. To examine potential relationships between brain activity and depressive symptomotology, percent intensity signal changes for high versus low importance advice in the MPFC and PCC were correlated with participants' self-report scores on the BDI (Beck, Ward, Mendelson, Mock, & Erbaugh, 1961). The correlation between BDI scores and signal change in the PCC was significant, r = .71; $p < .003$.

FIGURE 9
Average percent signal intensity change time courses compared to rest from the activated voxels bilaterally in the STS (x = +/–57, y = –47, z = 11) and MPFC (x = +/–5, y = 52, z = 32) respectively



Discussion

The aim of the current study was to examine the husbands' neurophysiological reactions to receiving directive advice from their wives. Previous research in the marital area has primarily relied on self-report and behavioral observation data. By examining the neurophysiological correlates of common interpersonal interactions within the context of marriage, we hope to both provide a new perspective for marital scholarship and to expand Theory of Mind work to the marital arena. The current findings support the conclusion that when individuals listen to advice, particularly high importance advice, they may recruit areas of the brain associated with attempting to discern the intentions of the advice giver. Specifically, it appears that directive advice may activate neural networks associated with mentalizing or ToM. This suggests that directive advice may be associated with attempting to decipher the advice giver's intentions. Compared to baseline, participants exhibited greater activation in the STS and MPFC, cortical areas associated with evaluative processing of social interactions. Several studies have reported results which are consistent with this interpretation of the data. Pelphrey and colleagues (2004) reported that the STS activation occurs when participants made judgments about intentional versus random actions of animated characters. Winston, Strange, O'Doherty, & Dolan (2002), found that both the STS and the MPFC were associated with tasks concerned with making judgments about the other's trustworthiness. Ochsner and colleagues (2004) observed activation in the STS and MPFC for participants making judgments regarding their own, rather than others', emotional state. Each of these studies supports the claim that the STS and MPFC are part of a distributed network selected for understanding the others' intentions (Frith & Frith, 2006).

The locations of certain activations for advice when compared with positive comments were unexpected. For example, although there was greater MPFC activation for high importance advice when compared with positive comments, the results were more dorsal than those reported in Pelphrey et al. (2004), however, and more consistent with those reported by Ochsner, Ray et al. (2004). This area of the brain has frequently been associated with response inhibition and emotion regulation (Hooley, Gruber, Scott, Hiller, & Yurgelun-Todd, 2005; Ochsner, Ray, et al., 2004; Phillips, Rauch, & Lane, 2003). Although speculative, it is possible that participants may have been attempting to regulate their emotions in response to the potential threat of advice on important topics.

Time course analyses demonstrated similar activation patterns across the three conditions (high and low importance advice and positive comments) in the STS, the MPFC, the group contrasts, and the ROI analyses. Specifically, advice was associated with greater signal amplitude in both the STS and MPFC than positive comments. Within the two types of advice, high importance advice exhibited greater amplitude in signal intensity than low importance advice (see Figure 9). This suggests that as the level importance increases, so does activity in ToM processing regions.

There was a modest relationship between percent signal intensity change in the PCC and husbands' BDI scores. Scholars suggested that the PCC may be part of an affective self-referential mnemonic network (Maddock, 1999; Maddock, Garrett, & Buonocore, 2003). Other studies have implicated the PCC's role in depressive symptomology (e.g., Bench, 1992). Congruent with these results, Beach and Gupta (2006) suggested that advice from one's spouse may be particularly deflating when depressed. From this perspective, while speculative, it is possible that greater activation in the PCC may represent the neurocognitive analog to this response, as the spouse ruminates and questions their self-worth while processing the advice.

The ROI laterality results were also relatively unexpected. Previous studies which have invoked ToM processing via biological motion (e.g., hand gestures, moving human silhouette) have observed greater activation in both the right STS and MPFC (Pelphrey et al., 2004; Winston et al., 2002). Our data indicated greater activation in both of these regions, but in the left hemisphere. This discrepancy may be due to differences in stimuli (i.e., visual motion versus verbal auditory stimuli). The aural and verbal nature of advice may have produced language processing in the left hemisphere. This raises further questions regarding potential differences in ToM processing for various stimuli.

The present results also have implications for social and cognitive theorizing, as well as marital therapy. Explanations, or attributions, of partner behavior have been shown to be robust predictors of marital outcomes (Bradbury & Fincham, 1990). Advice, especially in high importance areas, may prime individuals to question the intentions of the advice giver. That is, receiving performance feedback in a highly self-relevant area could lead one to question their partner's intentions, which has the potential to increase the likelihood of conflictual relationship behavior. Conflict promoting attributions were shown to be related to negative marital behaviors while giving social support (Beach, Fincham, Katz, & Bradbury, 1996; Bradbury, Beach, Fincham, & Nelson, 1996; Miller & Bradbury, 1995). Negative partner attributions have also been linked to less effective problem solving behaviors and heightened negative affectivity, e.g., crying or hostility (Bradbury & Fincham, 1992). It is possible that activation in the left STS may be related to the communicative character of the situation (i.e., the partner's intentions). Importantly, conflict-promoting attributions correlate with the tendency to reciprocate negative partner behavior (Bradbury & Fincham, 1993; Miller & Bradbury, 1995) and have been hypothesized to be a crucial variable for predicting change in marital satisfaction (Bradbury & Fincham, 1990). Likewise, negative attributions do not simply reflect general sentiments about the marriage (Bradbury et al., 1996) as manipulated attributions can influence behavior toward the partner (Bradbury & Fincham, 1988). Therefore, both correlational and experimental studies are consistent with the view that spousal cognitions, particularly attributions, strongly influence marital behavior. This area of inquiry deserves continued consideration and would likely benefit from further interdisciplinary collaboration (e.g., psychology, neuroscience, communication, and family studies).

In summary, advice was given at two different levels, high in importance to the self and low in importance to the self. Consistent with social comparison theorizing (Tesser et al., 1988), the level of activation in the STS and the MPFC rose significantly as the salience or potential threat of the advice increased. High importance advice demonstrated more striking activation differences, when compared with positive comments, than did low importance advice. Examining the neurocognitive correlates of advice provides an opportunity to pose questions that are difficult to answer using traditional psychological methodologies (Cacioppo, 2002). In the current study we hypothesized that directive advice would be associated with specific brain activation and that as the advice became more salient or threatening, greater activation would be observed in networks linked to social cognitive processing. This suggests that although advice is common within intimate relationships, individuals may have difficulty benefiting from it.

Limitations and future directions

The current study has limitations. Although the present sample size is common for neuroimaging experiments (e.g., Phillips et al., 1997), these results require replication. Despite the small sample size, the effects were sufficiently robust that significant results were evident despite having only 7 degrees of freedom. Finally, the current study's TE of 40 ms lacks T2* sensitivity in a 1.5T scanner. A TE of 60 ms would have improved signal detection; however, this was not feasible due to scanner limitations.

For future studies it may be useful to add an additional low-level linguistic baseline condition (e.g., neutral/irrelevant sentences). It is also possible that emotional prosody may have influenced participants' brain responses via emotional intonation differences. Thus, it may be useful to present sentences both visually and auditorily.

Brain imaging data was obtained only for men. There may be meaningful gender differences when responding to social cognitive information (Piefke, Weiss, Markowitsch, & Fink, 2005). Additionally, due to scanner limitations, functional imaging data was not collected for the entire brain. Future neuroimaging research should employ whole brain imaging for both men and women in order to examine gender-specific effects.

In addition, there were linguistic differences between the advice conditions and the positive comments. Therefore, these data should be interpreted with caution as the positive comments are not an ideal control. Furthermore, listening to personal comments from one's spouse inside of an MRI is a highly unusual situation. Like most brain imaging studies examining social cognitive processes, it is possible that participants' reactions were influenced by their very presence in an MRI. Finally, although we were able to observe significant differences for the ROI analyses, in light of the study's small sample size it is possible that we failed to detect certain brain activations due to insufficient power.

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