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Brain mapping of psychological processes with psychometric scales: An fMRI method for social neuroscience

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ABSTRACT

Introduction: The functional neuroimaging literature has used many stimuli (e.g., games, pictures, sounds) in fMRI studies to induce activation in brain areas related to psychological processes. To improve the link among psychological processes and their brain mapping, this study integrates the theory of measurement in the social sciences with the functional neuroimaging literature to propose a simple method that localizes the neural correlates of psychological processes using psychometric scales as stimuli to induce brain activation.
Materials and methods: Two fMRI studies were performed to illustrate this method with 30 subjects who responded to psychometric scales for four psychological processes on 7-point Likert-type anchors while their brains were being scanned in an fMRI. The first study examined two psychological processes–trust and distrust–whose neural correlates are known. The second study examined two psychological processes specific to technology use context–perceived usefulness and perceived ease of use–whose neural correlates are still unknown.
Results: Results from the first fMRI study confirmed the neural correlates of trust in the *caudate nucleus*, *putamen*, *anterior paracingulate cortex*, and *orbitofrontal cortex* and of distrust in the *amygdala* and *insular cortex*, thus confirming the literature. The second fMRI study identified the neural correlates of perceived usefulness in the *anterior cingulate cortex*, *caudate nucleus*, and *insular cortex* and perceived ease of use in the *dorsolateral prefrontal cortex*, which are consistent with the technology use literature.
Discussion: The proposed brain mapping method with psychometric scales can inform the *neurological* nature of psychological processes, challenge existing measurement assumptions, and help advance brain mapping.

Introduction

The potential to link brain activity to psychological processes (termed neural correlates) has attested the feasibility and value of brain mapping to the social sciences. The functional neuroimaging literature has used multiple stimuli (e.g., games, tasks, pictures, written scenarios, auditory cues) in fMRI studies to induce activation in brain areas that correspond to psychological processes (e.g., Delgado et al., 2005a,b; Paulus et al., 2003; Phan et al., 2004; Rustichini, 2005; Takahashi et al., 2004). However, there is still a need to improve the link among psychological processes and their corresponding neural correlates to create a stronger measurement connection between brain mapping and the social sciences. Such connection would enable both social scientists to better understand the underlying brain functionality of psychological processes to advance their neurological understanding of these processes, and also neuroscientists who seek to develop comprehensive functional maps of the human brain. Therefore, extending the theory of measurement in the social sciences that measures psychological processes with psychometric scales, we integrate the social sciences with the functional neuroimaging literature to propose a new theory-based brain mapping method that localizes the neural correlates of psychological processes using psychometric scales as stimuli to induce activation in the brain areas that are responsible for these psychological processes.

Psychological processes are conceptualized as high-order cognitive or emotional functions (Bagozzi and Edwards, 1998; Churchill, 1979) that can be measured with psychometric scales (Edwards and Bagozzi, 2000). The psychometric theory of measurement in the social sciences develops measures of psychological processes using measurement scales (Edwards, 2001). The theory of measurement focuses on the construction, refinement, and validation of multi-item measurement scales with appropriate measurement properties (Allen and Yen, 2002), such as construct validity and reliability (e.g., Bagozzi, 1993). A very common measurement approach is scaled or graded items along a continuum, such as Likert-type scales (Likert, 1932), which ask subjects to rate the degree to which they agree or disagree with a certain statement (Fig. 1). Integrating the psychometric theory of

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Overall, I found Website X to be easy to use.

1=Strongly Disagree 2 3 4=Neutral 5 6 7=Strongly Agree

Fig. 1. Graphical description of a 7-point Likert-type Scale for a sample measurement item. Overall, I found Website X to be easy to use. 1 = Strongly Disagree 2 3 4 = Neutral 5 6 7 = Strongly Agree.

measurement with the functional neuroimaging literature, this brain mapping method helps identify the neural correlates of psychological processes and quantify their level of brain activation. The multi-item scales serve as the stimuli that trigger brain activation whilst the subjects read the measurement items of the psychological processes. In an attempt to respond to each measurement item by selecting one of the values in a classic Likert-type scale, subjects engage the brain area that corresponds to the psychological process, thereby causing brain activation, which can then be captured by an fMRI scanner.

Our method draws upon the neuroimaging literature that used similar scales as fMRI stimuli. Kelley et al. (2002) showed subjects a set of words and asked whether the focal word describes themselves or other people; the subjects responded with yes/no responses with both hands. Johnson et al. (2002) asked subjects to evaluate their own mood, cognitive, and physical ability, and social skills with yes/no responses using auditory statements. Westen et al. (2006) presented subjects statements about the 2004 presidential candidates in the U.S. and asked them to rate their agreement to these statements on a 4-point Likert-type scale. Eddington et al. (2007) showed a subject's words about traits (social promotion and prevention) and asked them to respond to a 4-point Likert-type scale about how socially desirable the word was, how well it described a person, and how well it described themselves. Phan et al. (2004) asked subjects to rate their feelings about a picture they saw on a Likert-type scale as 1 = unpleasant, 2 = neutral, and 3 = pleasant and how much they associate themselves with the picture (1 = not at all, 2 = a little, 3 = a lot). Van Reekum et al. (2007) showed subjects pictures and asked them to assess them as positive or neutral (2-point scale), while Ochsner et al. (2004) asked subjects to rate how they feel about the picture (unpleasant, neutral, pleasant) using a 3-point Likert-type scale. Our proposed method extends these approaches by using well-established psychometric scales that were specifically developed in the social sciences to measure a psychological process. Thus, subjects are asked to evaluate the degree of a certain psychological process, which is proposed to trigger the corresponding brain area that relates to the focal psychological process.

To illustrate the proposed method, a total of four psychological processes were examined. Two psychological processes–trust and distrust–whose neural correlates are already known were first examined for validation purposes, and two other psychological processes from the specific context of technology use–perceived usefulness and perceived ease of use–whose neural correlates are still unknown were also examined for prediction purposes.

First, in terms of the expected neural correlates of trust, given that trust is associated with positive expected rewards by predicting a trustee's cooperative and benevolent future behavior (e.g., Gefen et al., 2003; Pavlou, 2003; Pavlou and Gefen, 2004), trust is expected to elicit activation in the brain's reward areas. The literature has linked the dorsal striatum to rewards and utility (e.g., Knutson et al., 2001), specifically the *caudate nucleus* and the *putamen* (e.g., Dimoka, 2010; Knutson and Peterson, 2005; King-Casas et al., 2005; McClure, et al., 2003). Moreover, given that trust deals with predicting whether the trustee will act cooperatively, the *anterior paracingulate cortex*, which is associated with social inferences (McCabe et al., 2001) is also expected to be activated. Besides, given that trust is about assuming the vulnerability associated with trusting a person to engage in a risky behavior (Pavlou and Gefen, 2005), the *orbitofrontal cortex*, a brain area associated with calculating uncertainty (Krain et al., 2006) is also expected to be activated. Second, in terms of the expected neural correlates of distrust, the *amygdala* and *insular cortex* are expected to be activated (Dimoka, 2010). The amygdala is activated in response to intense negative emotions (LeDoux, 2003), which is associated with distrust (Kramer, 1999). A lesion in the amygdala resulted in impaired judgment of untrustworthy people (Adolphs et al., 1998). The insular cortex, which has been linked to the fear of loss in the functional neuroimaging literature, (Wicker et al., 2003) is also expected to be activated in response to distrust (Lewicki et al., 1998). Moreover, Winston et al. (2002) and Todorov (2008) found amygdala and insular cortex activation in subjects who assessed untrustworthy people, implying that these two brain areas should be associated with distrust.

Second, while its neural correlates have not been explicitly identified in the neuroscience literature, perceived usefulness in the context of technology use should be associated with brain areas linked to utility and rewards (McClure et al., 2004), such as the caudate nucleus (Dimoka et al., in press). In contrast, low levels of perceived usefulness may be associated with negative utility or losses, such as the insular cortex (Wicker et al., 2003). In terms of the neural correlates of perceived ease of use, given that the ease of using a technology relates to cognitive thought, working memory, and problem solving (Davis, 1989), areas in the prefrontal cortex associated with executive thinking, such as the dorsolateral prefrontal cortex are expected to be activated. Nonetheless, this study follows an exploratory approach to identify the neural correlates of perceived usefulness and perceived ease of use, aiming to show how the proposed method can be used to infer the neural correlates of psychological processes.

It is important to note that each of these four psychological processes in this study is expected to elicit activation in more than one area in the brain. While a simple "one-to-one" mapping between a psychological process and a certain brain area would be straightforward, such a naïve interpretation is neurologically invalid, and a complex "many-to-many" relationship between psychological processes and brain areas better corresponds to the brain's functionality (e.g., Poldrack, 2006; Price and Friston, 2005). This is because a given psychological process usually activates more than a single brain area, while a certain brain area may be activated by more than one psychological process. Therefore, a certain brain activation does not necessarily suggest that a psychological process is involved (what is typically termed "reverse inference") (Miller, 2008). While reverse inference is not deductively valid and should not be used to draw conclusive inferences about the existence of certain psychological processes (Poldrack, 2006), it can still offer some exploratory insights as to candidate psychological processes that could potentially explain the observed brain activation (e.g., Cacioppo et al., 2008). Consequently, reverse inference should be used with extreme caution and only in an exploratory fashion to help explain the existence of certain brain activations.

Materials and methods

Two fMRI studies were conducted to test the proposed brain mapping method with four psychological processes that have well-

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established self-reported psychometric scales. The first study examined two psychological processes–trust and distrust–whose neural correlates have already been identified in the functional neuroimaging literature. The second study examined two psychological processes whose neural correlates have still not been identified–perceived usefulness and perceived ease of use–in the context of technology use. The objective of the first study was to validate the neural correlates of psychological processes that have already identified in the literature. The objective of the second study was to test the method with psychological processes whose neural correlates have *not* been identified in the neuroimaging literature, but where there is still ample literature on these processes in the social sciences to assess whether their neural correlates are consistent with their behavioral nature.

For each study, a different set of 15 right-handed subjects (roughly equal men and women) who were screened for fMRI safety (no medical implants, metal piercings, or physiological problems) participated for $35 compensation. The number of subjects was chosen to ensure adequate power of analysis (80%) for obtaining statistically-significant brain activations ($p<0.05$) (Desmond and Glover, 2002). The fMRI protocol was reviewed and approved by the University's Institutional Review Board. Technical details associated with the fMRI scanner and detailed data analysis procedures for both studies are reported in Table 1.

Study I method

For Study I, we created two fictitious sellers on eBay (www.ebay.com) to differ on their reputation of trust and distrust by experimentally manipulating the ratings and text comments on their feedback profile (Pavlou and Dimoka, 2006). Seller 1 was created to be high on trust and low on distrust, and Seller 2 was low on trust and high on distrust. Behavioral pretests confirmed that the levels of trust and distrust for these two sellers were statistically significant ($p<0.001$). Subjects were asked to review these two seller profiles before starting the fMRI study in order to become familiar with the two sellers that they would be asked to evaluate during the fMRI study.

Subjects then entered the fMRI scanner lying comfortably on their back. Visual stimuli were projected to them through fiber-optic goggles connected to a computer. Each of the two seller profiles was randomly shown for 3 s, which reminded subjects about each seller without asking them to read the entire profile. This was followed by a randomly-chosen measurement item. The exact measurement items for trust and distrust are shown in Table 2, and they are based on well-established psychometric scales for trust (e.g., Gefen et al., 2003; Pavlou, 2003) and distrust (e.g., Cho, 2006; Hsia, 2002; McKnight and Choudhury, 2006), respectively. Then, 5 s later, the Likert-type scales, which were anchored at "1 = Strongly Disagree" to "7 = Strongly Agree" (Fig. 1), appeared on the screen, which also served as a signal to subjects to select their response. Subjects selected their response by depressing one of seven buttons on the computer screen using a fiber-optic mouse in close proximity to their right hand. Then, they were shown a fixation cross for 4 s, followed by a new randomly selected seller profile (Seller 1 or Seller 2), and a randomly selected measurement item (Table 2) for a randomly selected psychological process (trust or distrust). Brain activation was captured while subjects were reading each measurement item, before they were shown the Likert-type scale. This procedure was repeated for all 10 measurement items for trust and distrust (Table 2).

Since fMRI studies require appropriate control variables to "cancel out" spurious activation (e.g., visual stimuli, movement, other sources of noise) and isolate brain activation due to the experimental stimuli, for controls, the subjects were randomly shown each of the two sellers together with a statement (that resembled the measurement items in terms of format and length) asking them to press one of the seven buttons on the 7-point Likert-type scale. Brain activation while subjects were reading these control statements was subtracted from the brain activation while they were processing the measurement items for the focal psychological processes.

Upon completion of the experiment, the subjects were thanked, debriefed, and dismissed.

Table 1
Technical details.

Equipment: The fMRI scanner was a 3 Tesla, Siemens whole-body scanner with a standard CP head coil. Subjects were scanned with contiguous (no gap) 5 mm axial high-resolution T1-weighted structural slices (matrix size = 256 × 256; TR = 600; TE = 15 ms; FOV = 21 cm; NEX = 1; slice thickness = 5 mm) were collected for spatial normalization procedures, and overlay of functional data. Precise localization based on standard anatomic markers (AC-PC Line) was used for all subjects (Talairach and Tournoux, 1988). Functional scans were acquired with a gradient-echo planar free induction decay (EPI-FID) sequence (T2*weighted: 128 × 128 matrix; FOV = 21 cm; slice thickness = 5 mm; TR = 2 s; and TE = 30 ms, slices = 28) in the same plane as the structural images. Voxel size was 3.33 mm × 3.33 mm × 5 mm.
Data pre-processing: The data were processed using SPM5 (Statistical Parametric Mapping, Wellcome Department of Cognitive Neurology, University College of London, UK) under Matlab® (The Mathworks, Inc., Natick, MA). Slice timing correction was performed in order to compensate for delays associated with acquisition time differences among slices during sequential imaging. A 3D automated image registration routine (six-parameter rigid body, sinc interpolation; second order adjustment for movement) was applied to the volumes to realign them with the first volume of the first series used as a spatial reference. All functional and anatomical volumes were then transformed into standard anatomical space using the T2 EPI template and the SPM5 normalization procedure (Ashburber and Friston, 2005). Next, all volumes underwent spatial smoothing by convolution with a Gaussian kernel of 8 cubic mm full width at half maximum (FWHM) to increase the signal-to-noise ratio (SNR) and account for inter-session differences.
Statistical data analysis: Subject-level analyses based on changes in Blood Oxygenation Level Dependent (BOLD) contrasts were performed with the General Linear Model (GLM) in SPM5. The two conditions (high trust–low distrust Seller 1 versus low trust–high distrust Seller 2 for Study 1 and high usefulness/high ease of use Website 1 versus low usefulness/low ease of use Website 2) were modeled with a canonical hemodynamic response function (hrf). Contrast maps were obtained through linear contrasts of all event types. Group-level random effects analyses for main effects were accomplished by entering whole brain contrasts into one-sample t tests. For the group level analysis, Region of Interest (ROI) analysis was implemented, which involves defining a specific area of interest in the brain within which to make local measurements. A significance threshold based on spatial extent using a height of $t \geq 1.96$ and cluster probability of an uncorrected $p \leq 0.05$ (Forman et al., 1995) was applied to the areas of interest.

Table 2
Measurement items for trust and distrust (Study 1).

Process	Psychometric measurement item
Trust 1	[Seller] has the expertise to understand my needs and preferences.
Trust 2	[Seller] has the ability to effectively undertake this transaction.
Trust 3	[Seller] will deliver this product according to the posted delivery terms.
Trust 4	[Seller] is likely to be credible during this transaction.
Trust 5	[Seller] is likely to care about my well-being during this transaction.
Trust 6	[Seller] will keep my best interests in mind during this transaction.
Trust 7	If there is a problem with this auction, [Seller] will go out on a limb for me.
Trust 8	[Seller] is likely to make sacrifices for me during this auction, if needed.
Trust 9	[Seller] will deliver this product according to the posted delivery terms.
Trust 10	I believe I can count on [Seller] to deliver this product to me.
Distrust 1	I feel cautious about characterizing this [Seller] as honest.
Distrust 2	I am skeptical that [Seller] is competent in sending this product on time.
Distrust 3	I am worried that [Seller] would not be truthful in its dealings with me.
Distrust 4	It is unclear whether [Seller] would keep its promises and commitments.
Distrust 5	I suspect [Seller] is interested in just its own well-being, not mine.
Distrust 6	[Seller] is likely to engage in a harmful behavior toward me.
Distrust 7	I believe [Seller] will perform this auction in a fraudulent way.
Distrust 8	I am doubtful that this [Seller] would act in my best interests.
Distrust 9	I am fearful that [Seller] would *not* do its best to help me.
Distrust 10	I am uneasy about whether [Seller] is likely to be sincere with me.

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Table 3
Measurement items for perceived usefulness and ease of use (Study 2).

Process	Psychometric measurement item
Usefulness 1	Website X was useful in getting valuable information about this camera.
Usefulness 2	Website X was useful for getting information about this camera.
Usefulness 3	Using Website X enabled me to find information about this camera.
Usefulness 4	Website X improved my performance in searching for this camera.
Usefulness 5	Website X enhanced my effectiveness in learning about this camera.
Usefulness 6	Website X helped me get information about this camera quickly.
Usefulness 7	Using Website X helped me learn useful information about this camera.
Usefulness 8	Website X offered useful information about this camera.
Usefulness 9	Website X was valuable in learning about this camera.
Usefulness 10	Using Website X enabled me to get useful information about this camera.
Ease of Use 1	Learning to use Website X would be easy for me.
Ease of Use 2	My interaction with Website X would be clear.
Ease of Use 3	Learning to use Website X would be easy.
Ease of Use 4	It would be easy to become skillful at using the Website X.
Ease of Use 5	I would evaluate Website X to be easy to use.
Ease of Use 6	My interaction with Website X would be straightforward.
Ease of Use 7	It would be easy for me to learn to use Website X.
Ease of Use 8	Website X can be regarded as a user friendly website.
Ease of Use 9	I would evaluate Website X as a comprehensible website.
Ease of Use 10	Overall, I found Website X to be easy to use.

Study 2 method

For Study 2, we also created two fictitious commercial websites to differ on their level of functionality (usefulness) and user friendliness (ease of use) by experimentally manipulating their attributes. Website 1 was created to be high on usefulness and ease of use and Website 2 was created to be low on usefulness and ease of use. Behavioral pretests with a different set of subjects confirmed that the levels of perceived usefulness and ease of use for the two websites were statistically significant ($p<0.001$) using the exact same measurement items for these two psychological constructs as in the fMRI study (Table 3). Before entering the fMRI scanner, subjects were asked to review and become familiar with the two websites in a fictitious scenario in which they were asked to learn and purchase a digital camera from each of the two websites.

A different set of 15 subjects from study 1 then entered the fMRI scanner lying comfortably on their back. Visual stimuli were also projected to them through fiber-optic goggles connected to a computer. Each of the two websites was randomly shown for 3 s, which reminded subjects about each website without asking them to browse the entire website (Fig. 2). Each website was followed by a randomly chosen measurement item for perceived usefulness and ease of use (Table 3), which were based on well-established psychometric scales for perceived technology usefulness and perceived ease of technology use (Davis, 1989; Pavlou, 2003). 5 s later the Likert-type scales, which were anchored at "1 = Strongly Disagree" to "7 = Strongly Agree" (Fig. 1), appeared on the screen that signaled subjects to choose their response. Subjects chose their response by pressing one of the seven buttons on the computer screen using a fiber-optic mouse with their right hand. Then they were shown a fixation cross for 4 s, followed by a new randomly selected website (Website 1 or Website 2) and a randomly selected measurement item (Table 3) for the two focal psychological process (perceived usefulness or perceived ease of use). Brain activation was captured while subjects were reading each of the 10 measurement items before they were shown the Likert-type scale. This process was repeated for all measurement items for usefulness and ease of use (Table 3). A similar procedure to Study 1 was followed for the control variables with similar statements in terms of format and length. Finally, as in Study 1, upon completion of the fMRI experiment, subjects were also thanked, debriefed, and dismissed.

Comparison between brain and psychometric data

Since the psychometric scales ask subjects to rate the level of each psychological process on a 7-point scale (Fig. 1), it is possible to compare the self-reported level for each process with the level of activation in the brain areas that corresponds to the psychological process. While correlations between the levels of brain activation and self-reported measures of psychological processes are usually based on self-reported measures captured *outside* the fMRI scanner, this study aims to provide a more time-sensitive correlation by comparing the level of brain activation when the subject reads and processes each measurement item with the corresponding self-reported level on the very same measurement item on a Likert-type scale. This would also allow us to compare the correlations between the "objective" brain activations with their corresponding self-reported "subjective" measures across psychological processes at the same time (versus comparing with self-reported measures before or after the fMRI study).

Results

The technical details of the data analysis procedure for the fMRI data are shown in Table 1.

Study 1 results

The fMRI results of Study 1 for trust and distrust are shown in Fig. 3 and Table 4.

Trust

As shown in Fig. 3, the High-Trust/Low Distrust Seller 1 elicited significant activation in the *caudate nucleus* ($z=3.52$, $p<0.01$), *putamen* ($z=2.98$, $p<0.01$), and *anterior paracingulate cortex* ($z=3.71$, $p<0.001$). The caudate nucleus and putamen are part of the brain's "reward" center (e.g., Knutson and Peterson, 2005; McClure, et al., 2003; O'Doherty, et al., 2004), and they have often been associated with trust (e.g., Dimoka, 2010; King-Casas et al., 2005). The anterior paracingulate cortex is associated with social inferences (McCabe et al., 2001), and it captures whether one will act cooperatively. Besides, the Low-Trust/High Distrust Seller 2 only elicited activation in the *orbitofrontal cortex* ($z=3.11$, $p<0.01$), an area associated with calculating uncertainty (Krain et al., 2006). These findings are consistent with the literature that views the

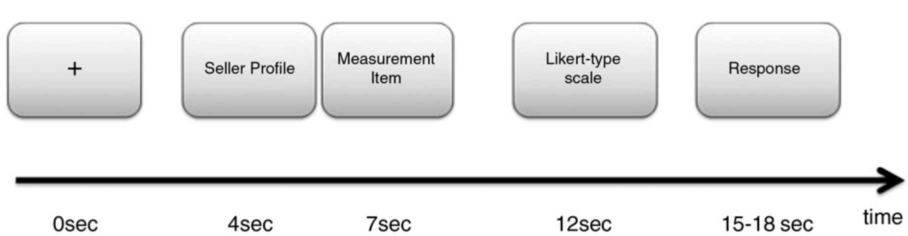

Fig. 2. Graphical illustration of the experimental task for both studies.

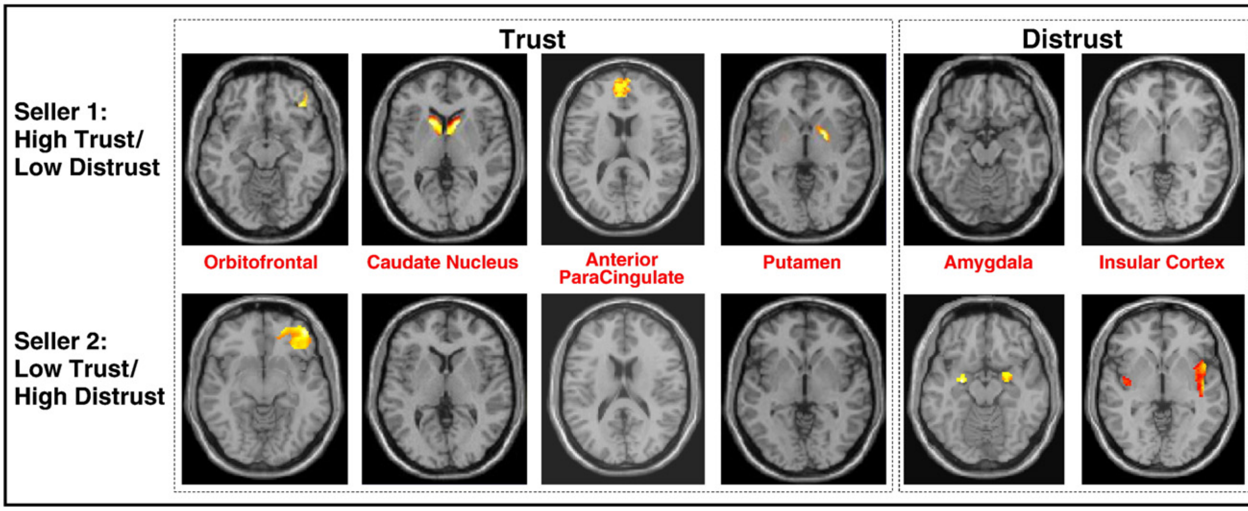

Fig. 3. The neural correlates of trust and distrust.

psychological process of trust as a trustor's willingness to assume uncertainty (orbitofrontal cortex) by predicting that a trustee will act cooperatively (anterior paracingulate cortex based on confident expectations about positive rewards (caudate nucleus and putamen) In sum, these findings both correspond with the functional neuroimaging literature in terms of the neural correlates of trust and also with the behavioral nature of trust in the social sciences.

Distrust

Low Trust–High Distrust Seller 2 elicited significant activation in bilateral *amygdala* ($z = 2.38$, $p < 0.05$) and bilateral *insular cortex* ($z = 2.85$, $p < 0.05$). The amygdala has been linked to intense negative emotions (LeDoux, 2003); Adolphs et al. (1998) found that a lesion in the amygdala is linked to impaired judgment of untrustworthiness assessment. The insular cortex has been linked to the fear of loss in the functional neuroimaging literature (Wicker et al., 2003). The findings in the amygdala and insular cortex are also consistent with Winston et al. (2002) and Todorov (2008) who found bilateral amygdala and insular cortex activation when assessing untrustworthy people, and also with the distrust literature in the social sciences that involves fear of anticipated loss (insular cortex) and vigilance against danger or betrayal (Hardin, 2001).

Table 4 shows the correlations of the levels of brain activation in the neural correlates of trust and distrust with their corresponding psychometric measurement scales. While all correlations are statistically significant ($p < 0.05$), they are not extremely high (range $|r| = 0.18–0.51$), largely because Lieberman et al.'s (2009) guidelines for avoiding correlation bias were followed, notably selecting activated voxels in functional Region of Interest (ROI) analysis without knowledge of the behavioral data. Also, the correlations in the areas associated with trust (orbitofrontal cortex, caudate nucleus, putamen, and anterior paracingulate cortex) are significantly higher ($p < 0.01$) than the ones of distrust (insular cortex and amygdala), implying that subjects can better represent their self-reported evaluations of trust in a way that corresponds to their brain activations, while their self-reported evaluation of distrust is significantly worse. Perhaps the areas associated with distrust (insular cortex and amygdala) explain these low correlations ($r = 0.18$ and $r = 0.19$, respectively) because people may have a more difficult time self-reporting their perceptions of distrust than their perceptions of trust (Dimoka, 2010). Nonetheless, all correlations are statistically significant, testifying the method's ability to identify and quantify the levels of brain activation to correspond to the subjects' self-reported measures on the corresponding psychometric scales of these psychological processes.

In sum, the results of Study 1 support the method's ability to localize the neural correlates of two psychological processes to both correspond to the functional neuroimaging literature and also to the nature of these processes in the social sciences. Besides, the significant correlations between the self-reported evaluations of the levels of these psychological processes and their corresponding levels of brain activation support the statistical association between the stimuli (psychometric measurement items) and their resulting effects (brain activations).

Table 4
Correlations between level of brain activations and psychometric scales of trust and distrust (Study 1).

Psychological process	Orbitofrontal cortex	Caudate nucleus	Putamen	Anterior paracingulate cortex
Trust	−0.51***	0.38**	0.36**	0.21*

Psychological process	Insular cortex	Amygdala
Distrust	0.18*	0.19*

Study 2 results

The fMRI results of Study 2 for usefulness and ease of use are shown in Fig. 4 and Table 5.

Perceived usefulness

As shown in Fig. 4, the High-Usefulness/High Ease of Use Website 1 elicited activation in the *anterior cingulate cortex* ($z = 2.34$, $p < 0.05$) and *caudate nucleus* ($z = 2.12$, $p < 0.05$). These areas are also part of the brain's "reward" areas (McClure et al., 2004); specifically the caudate nucleus is associated by the magnitude of a reward (Hsu et al., 2005) and the anterior cingulate cortex with the anticipation of the reward (Bush et al., 2002). The Low Usefulness/Low Ease of Use Website 2 elicited significant activation in the *insular cortex* ($z = 3.01$, $p < 0.01$). The insular cortex has been linked to the fear of loss (Wicker et al., 2003).

While the neural correlates of perceived usefulness have not yet been identified in the functional neuroimaging literature, these identified areas correspond to their description in the social sciences (specifically the technology use literature) in the sense that high

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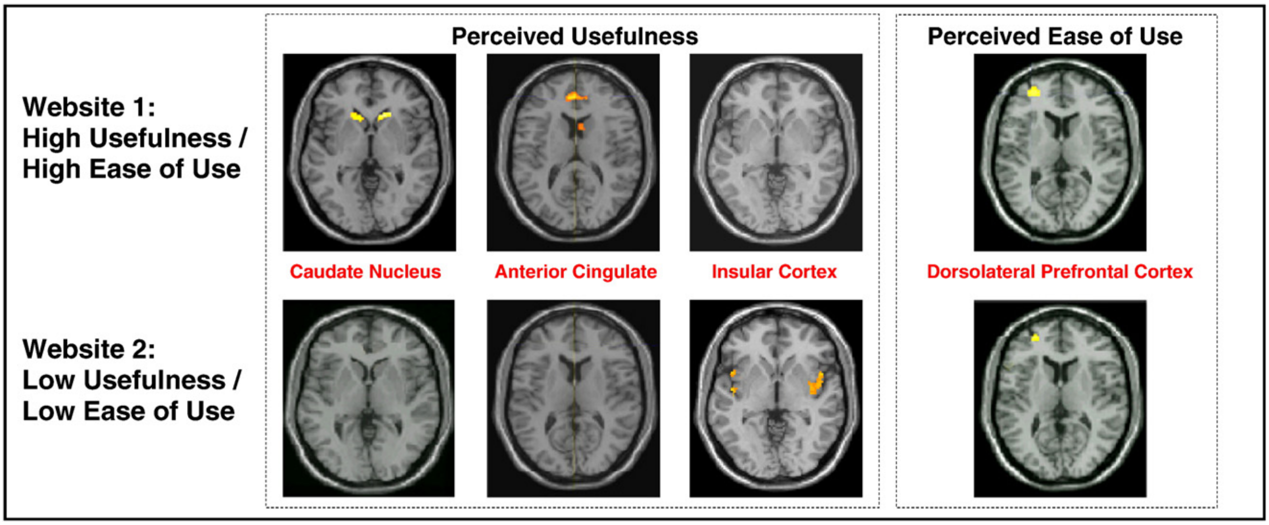

Fig. 4. The neural correlates of perceived usefulness and perceived ease of use.

perceived usefulness is associated with expectations of increased utility and rewards from using the technology (such as a functional website), and this is why perceived usefulness is mapped onto the brain's reward areas (Knutson and Cooper, 2005). In contrast, a poorly designed technology (website) is associated with low levels of perceived usefulness, which is mapped in the brain as a potential for loss (insular cortex) from using the website for transactions.

Perceived ease of use

Both websites elicited activation in the *dorsolateral prefrontal cortex.* Website 1, which was perceived easier to use (verified by the self-reported responses), elicited significantly higher activation ($z=3.14$, $p<0.01$) than Website 2 ($z=2.37$, $p<0.05$). The dorsolateral prefrontal cortex is linked to cognitive appraisal (Rypma and D'Esposito, 1999), working memory (Linden et al., 2003), and problem solving (Stuss and Alexander, 2000). While perceived ease of use has not been studied in the functional neuroimaging literature, its neural correlates correspond to findings in the technology use literature since perceived ease of use is mapped onto areas linked to assessing the cognitive resources needed to use a technology (website).

Table 5 reports the correlations of the levels of brain activation in the neural correlates of perceived usefulness and perceived ease of use with their corresponding psychometric scales. All correlations are statistically significant ($p<0.01$), and somewhat high (range $|r|=$ 0.57–0.69). This is perhaps because the psychological processes of perceived usefulness and ease of use are generally viewed as highly cognitive processes (Davis, 1989), and it is relatively easier for subjects to self-report their evaluation of a technology's (website's) usefulness and ease of use (relative to trust and distrust, for example, as noted in Study 1).

Table 5
Correlations between level of brain activations and psychometric scales of perceived usefulness and perceived ease of use (Study 2).

Psychological process	Caudate nucleus	Anterior cingulate cortex	Insular cortex
Usefulness	0.59***	0.69**	−0.57**
Psychological process		Dorsolateral prefrontal cortex	
Ease of use		0.58***	

***Significant at $p<0.001$; **Significant at $p<0.01$; *Significant at $p<0.05$.

The results of Study 2 support the method's ability to localize the neural correlates of psychological processes that have not been examined in the functional neuroimaging literature. Not only the identified neural correlates do correspond to the literature in the social sciences, but also the correlations between the self-reported evaluations of these psychological processes and their corresponding levels of brain activation further support the proposed method. Besides, the results of Study 2 contribute to the technology adoption and use literature (Davis, 1989) by helping infer the neural correlates of the two primary psychological processes that predict a user's technology use, thus helping integrate the technology adoption and use literature with the functional neuroimaging literature.

Integrating the results of Study 1 and Study 2

The results of both studies suggest that it is possible to use existing psychometric scales as stimuli to help identify the neural correlates of psychological processes in the social sciences. The combination of localizing the brain areas activated by well-established psychometric scales of two psychological processes whose neural correlates have already been identified in the literature (Study 1) with localizing the brain areas of two psychological processes whose neural correlates have not yet been identified in the literature (Study 2) supports the proposed brain mapping method. Moreover, the levels of activation in the neural correlates of these psychological processes are significantly correlated with their corresponding self-reported measures on Likert-type scales, further supporting the validity of this method to accurately localize the level of brain activation. In sum, both studies render support for the method's ability to localize the neural correlates of psychological processes with the aid of psychometric scales.

Both trust and perceived usefulness activate the caudate nucleus. Activation in the same brain area does not imply that the proposed method cannot precisely infer the neural correlates of psychological processes since two or more psychological processes can activate the same brain areas (e.g., Cacciopo et al., 2008; Miller, 2008; Poldrack, 2006), as discussed earlier. Specific to trust and perceived usefulness, activating the caudate nucleus is consistent with the nature of these psychological processes that are both associated with positive

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rewards. In fact, the literature has shown that the behavioral measures of trust and perceived usefulness are highly correlated (e.g., Gefen et al., 2003; Pavlou, 2003). In the context of technology use, a certain technology, such as a website that is trusted by its users to deliver on its promise is likely to be perceived as more useful by its users (Pavlou and Fygenson, 2006). In contrast, a technology that is not trusted is unlikely to be used, thereby limiting its perceived usefulness. Thus, the common neural correlates of these psychological processes helps offer a neurological explanation to their significant correlation reported in the technology adoption and use literature, thus helping integrate the technology use and trust literatures.

Discussion

The study's most important contribution is to give social neuroscientists a relatively simple method for localizing psychological processes that rely on classic psychometric scales that are specifically developed to measure these processes as direct stimuli for inducing brain activation. The proposed method can help create maps of brain activations that specifically correspond to psychological processes without the need to resort to indirect stimuli, such as economic games, cognitive tasks, or visual pictures. The psychometric theory of measurement has either developed well-established psychometric scales for measuring psychological processes or offers guidelines for developing new psychometric scales with proper measurement properties. Thus, social neuroscientists can rely on these scales to induce brain activation specifically for existing or newly developed psychological processes. In doing so, it is possible to have a "common language" to readily compare brain activations across studies that use the same psychometric scales as stimuli, thus overcoming the difficulty in comparing across studies that use diverse stimuli, especially fMRI studies that aim to induce brain activation for presumably the very same psychological process (e.g., trust) using trustworthy faces (Winston et al., 2002) or the "trust game" (Delgado et al., 2005a,b) as stimuli. The proposed method could thus facilitate the creation of functional maps of the human brain that would include both existing processes and also new psychological processes that are likely to be developed in the social sciences.

Before discussing the method's implications, it is necessary to acknowledge its limitations. Psychometric scales are susceptible to several measurement biases, such as subjectivity and social desirability bias. First, psychometric self-reported measures are inherently subjective and may not perfectly correspond to a person's revealed preference. While the brain may reveal objective brain activity and mitigate subjectivity bias, stimuli that reveal true preference may be still be useful. Second, subjects may respond to psychometric scales in a politically correct way, thereby hiding their true perceptions. While the brain may uncover any such hidden perceptions, it is necessary to realize that brain activity may be biased by "politically-correct" self reporting.

The proposed brain mapping method for identifying the locale and level of activation of the neural correlates of psychological processes with the aid of psychometric scales can inform the social sciences about the *neural basis* of psychological processes, thus enhancing our understanding of the nature of these processes. This method can also be used to challenge behavioral assumptions in the social sciences in several ways: First, it can help specify the dimensionality of psychological processes by examining the brain areas that are activated by their corresponding psychometric scales. If a psychological process spans several brain areas with distinct functional attributions, the process may indeed be multi-dimensional. Consequently, the method can help refine the conceptualization of existing psychological processes to better correspond to the brain's functionality. Second, this method can help determine whether two seemingly unrelated psychological processes are conceptually distinct. If their respective psychometric scales activate the exact same brain areas, they may exhibit a commonality that could not have been inferred with existing measurement approaches, especially if those may have inflated their empirical distinction (discriminant validity). Third, this method may offer a neurological explanation to existing associations among psychological processes, such as the high correlation between trust and perceived usefulness observed in the literature, which may be explained by their common activation in the caudate nucleus in this study. Fourth, while psychometric scales of psychological processes are explicitly developed to be linear and continuous, their corresponding brain activations often exhibit non-linearities, such as those observed in this study in which different brain areas are activated for the high versus low levels in the presumably linear and continuous psychometric scales of trust and perceived usefulness (which is common in the psychometric theory of measure literature). Thus, the proposed method may help refine the psychometric theory of measurement to develop new psychometric scales that better correspond to the brain's (presumably non-linear) functionality. Taken together, the proposed method opens several opportunities for the social sciences to enhance the understanding of psychological processes by understanding their neural correlates, particularly since it allows a more direct comparison between the direct psychometric scales of the focal psychological process with the resulting brain activations that they are proposed to induce.

Besides rendering support for the proposed method, the observed significant correlations between the self-reported psychometric scales and the levels of brain activation in their corresponding neural correlates have implications for drawing direct comparisons between these two distinct sources of measurement. However, a tail of caution was raised that the correlations between psychometric measures and brain activations may be "implausibly high" (Vul et al., 2009, p. 274). The test–retest reliability tests that presumably present an upper bound to the possible correlations are based on collecting behavioral and fMRI data at different points in time (p. 275), usually comparing fMRI data with behavioral data outside the fMRI scanner. The current method collects behavioral and fMRI data virtually at the same time (brain activation is captured just before selecting a response on the psychometric 7-point scale), thus enabling a more time-sensitive test of the actual correlations between self-reported and brain data. Coupled with following Vul et al.'s (2009) and Saxe et al.'s (2006) guidelines for selecting voxels based on functional considerations (independent of the behavioral data), it is possible to have a more realistic way to measure the level of correlation between behavioral and brain data, at least by allowing the measurement of both sources of data together in time.

While not explicitly identified in these two studies, it is possible that the psychometric scales of psychological processes induce activation in brain areas that uncover new insights about the nature of these processes that do not correspond to existing theories in the social sciences. Such "hidden" brain areas may be unconsciously triggered when subjects respond to the psychometric scales, but they may not surface in their self-reported responses since some processes may not be subject to introspection, such as automated or emotional processes, or subjects may be unable, uncomfortable, or unwilling to truthfully self-report on processes that may be considered sensitive to them, such as questions on sensitive or controversial issues. Accordingly, the proposed method may be used in an exploratory fashion to identify potentially "hidden" aspects of psychological processes that are not captured by existing methods.

The objective nature of brain data could add tremendous value to the social sciences by complementing the subjective nature of self-reported psychometric scales. Therefore, we hope the proposed method that aims to shed light on the link between psychological processes and their corresponding neural correlates entices social scientists to integrate neurological explanations to the discussion of the nature of psychological processes, thereby complementing existing behavioral explanations with neurological theories. First,

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the underlying brain activity can guide theory development and help test competing theories. For example, if two competing theories predict different underlying psychological processes to explain a certain phenomenon, the localization of activity in the brain can assess which psychological process is more likely to explain the phenomenon, thus enhancing the descriptive power of psychological theories. Second, the proposed method can help mitigate omitted variable bias by helping uncover missing psychological processes that may not have been fully inferred by behavioral theories. For example, if a stimulus elicits activation in a brain area that corresponds to a known psychological process, it may help reduce omitted variables from existing behavioral theories.

Finally, the ultimate purpose of this brain mapping method is to create a comprehensive functional map of the human brain that corresponds to the many psychological processes in the social sciences. We hope this method will bridge the gap between the functional neuroimaging literature and the social sciences by helping develop a more straightforward connection among psychological processes and their corresponding neural correlates.

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