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# **Incorporating Social Presence in the Design of the Anthropomorphic Interface of Recommendation Agents: Insights from an fMRI Study**

*Completed Research Paper*

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## **Abstract**

Recommendation agents (RAs) are regularly used in online environments to give consumers advice on products. Since social components of human-like RAs (humanoid avatars) are important components in their adoption and use, this study focuses on how the design of the anthropomorphic interface of RAs in terms of social demographics, namely ethnicity and gender, can enhance the RA's social presence to facilitate their adoption. Since social presence has been shown in the literature to predict the adoption and use of RAs, we examine whether match or mismatch in terms of the anthropomorphic RA's ethnicity and gender can enhance the user's social interaction with an RA.

To overcome concerns of social desirability bias and political correctness when users assess the social presence of RAs that vary in their ethnicity and gender, we conducted a functional Magnetic Resonance Imaging (fMRI) study to complement a traditional behavioral experiment. Our goal was to explain prior behavioral findings that showed that ethnicity (as opposed to gender) match is associated with higher social presence, particularly among women. Specifically, brain activity was captured in an fMRI scanner while users who varied on their ethnicity and gender to either match or mismatch the ethnicity and gender of four RAs evaluated each of the RAs on their social presence.

Besides contributing to the neuroscience literature by identifying the brain activations that relate to social presence, the fMRI results shed light on the nature of social presence and explain earlier behavioral findings by showing gender differences in the neural correlates of social presence in terms of ethnicity and gender match and mismatch. Implications on designing anthropomorphic interfaces to embody social demographics to enhance social presence are discussed.

*Keywords:* Online Recommendation Agents, Anthropomorphic Interfaces, Ethnicity, Gender, NeuroIS, Neuroscience, fMRI.

## Introduction

Recommendation agents (RAs) are frequently used in online environments to give consumers advice on products. By eliciting consumers' needs and advising them of available products that best match their needs, RAs improve decision-making efficacy and reduce cognitive effort (Xiao and Benbasat, 2007). In fact, RAs have assumed some of the traditional roles of human salespeople with automated advice (e.g., Alba et al., 1997; Senecal and Nantel, 2004). While RAs have the potential to enhance consumer decision-making and improve the quality of product purchases, their use is still modest (e.g., Leavitt, 2006). This is mainly because the literature on recommendation agents has focused on their functional and utilitarian features (e.g., Xiao and Benbasat, 2007), thus ignoring their social aspects. Social cues, such as ethnicity and gender, are major predictors of the adoption and use of RAs (Qiu and Benbasat, 2010), particularly if RAs have a humanoid embodiment with an anthropomorphic (human-like) interface, similar to traditional salespeople whose social demographics are important drivers of their success (Jones et al., 1998).

This study focuses on how the design of the anthropomorphic interface of RAs in terms of social demographics (ethnicity and gender) can enhance a user's perception of the degree of *social presence* when interacting with a RA. Because social presence has been extensively shown to predict the adoption and use of RAs by interacting with their users to ask questions about their needs and offer product advice (Qiu and Benbasat, 2009), we examine whether a demographic match or mismatch with an anthropomorphic RA's ethnicity and gender can enhance the user's perception of social presence and her intention to use the RA. Accordingly, this study focuses on the design of the anthropomorphic interface between users and the humanoid RAs in an attempt to enhance their social interaction. Social presence captures the social aspect of the user-RA interaction, and it focuses on the relational nature of the human computer interaction that is captured by social feelings of intimacy and warmth (Kumar and Benbasat, 2006).

In this study, we used functional Magnetic Resonance Imaging (fMRI) to measure the brain activity while subjects interact with human-computer interfaces in the form of RAs. By being able to directly measure brain activity, functional neuroimaging tools, such as fMRI, have been shown to shed light on many unanswered questions in the economics (e.g., Camerer, 2003; Glimcher and Rustichini, 2004), marketing (e.g., Lee *et al.*, 2006), and psychology (e.g., Pessoa, 2008) literatures. The use of neuroimaging tools has also been extended to the IS and HCI literatures. In fact, there is much interest among IS researchers in exploring the potential of NeuroIS, and several studies with neuroimaging data appeared in prominent IS journals (e.g., Cyr et al., 2009; Dimoka, 2010a; Dimoka et al., 2010; Dimoka and Davis, 2008; Dimoka et al., 2007; Galletta et al., 2007; Minnery and Fine, 2009; Moore et al., 2005). We conducted a functional Magnetic Resonance Imaging (fMRI) study to explain behavioral findings that showed that ethnicity (as opposed to gender) match is associated with higher social presence, particularly among women (Qiu and Benbasat, 2010). Direct brain data help overcome concerns of social desirability bias and political correctness when users assess the social presence of RAs that vary in their ethnicity and gender. Most importantly, we wanted to obtain a deeper (neurological) understanding of these behavioral findings. Specifically, brain activity was captured in an fMRI scanner while users who varied on their ethnicity and gender to either match or mismatch the ethnicity and gender of four RAs evaluated each of the RAs on their perception of social presence. The fMRI study was undertaken to complement the psychometric (behavioral) measurement of social presence by capturing the location, timing, and level of brain activity that underlies social presence (termed neural correlates). fMRI measures the brain's metabolic activity using the blood's magnetic properties with superb spatial resolution (Dimoka, 2010b). We drew upon the neuroscience literature to link the identified brain activations that correspond to social presence to existing neurological processes, aiming to reveal rich insights on the nature of social presence. To our knowledge, this is the first study on the design of RAs that uses a multi-method (behavioral with fMRI) approach to achieve a comprehensive understanding of the role of the human-computer interface on social presence.

Earlier behavioral work has identified gender differences in terms of how female and male users interact with RAs, notably that women tend to rely more on social cues – ethnicity and gender – than men (Qiu and Benbasat, 2010). To help identify the neurological origins of these gender differences, the fMRI study separately examined the neural correlates of social presence in women and men. In sum, the following two research questions guided this paper:

1. What are the neural correlates of social presence in the context of human-computer interaction between users and RAs that are matched or mismatched in terms of ethnicity and gender, and what can we learn from the neuroscience literature in terms of their localization in the brain?
2. What are the neurological differences between women and men in terms of assessing the social presence of RAs that either match or do not match their ethnicity and gender? Can we explain these gender differences in terms of the observed neural correlates of social presence?

The fMRI results show that the neural correlates of social presence are quite different among women and men. While social presence due to ethnicity and gender match activated brain areas linked to *social inferences* in women (as theorized), social presence activated (non-hypothesized) brain areas related to *utility* in men. There were also (non-hypothesized) activations in brain areas related to *fear of loss* due to lack of social presence for RAs that differed on their ethnicity and gender, which were stronger in women. These results offer a neurological explanation to the observed behavioral gender differences and also offer interesting findings about the nature of social presence.

## **Theory Development**

### ***Design of Anthropomorphic Interface of Online Product Recommendation Agents***

For online RAs to appeal to their users, their human-computer interface is often designed with an anthropomorphic embodiment to imitate traditional human communication (Qiu and Benbasat, 2009). The human-like features of RAs and their social cues are important design considerations with implications for their adoption and use because users perceive a human-like, social, and interpersonal communication when interacting with RAs (Komiak and Benbasat, 2006). The literature has noted the importance of demographic cues in the design of RAs with anthropomorphic interfaces (Baylor and Ryu, 2003; Cowell and Stanney, 2005; Nass et al., 1995). This is because demographic cues, such as ethnicity and gender, are two of the most instinctive demographic characteristics that a person readily observes when looking at another (virtual) person (e.g., Elsass and Graves, 1997; Phelps et al., 2000).

### ***Similarity-Attraction, Homophily, and Social Identity Theory***

The importance of social affiliation with a salesperson has long been an important driver of consumer behavior (Westbrook and Black, 1985). Accordingly, extrapolating from human to computer-based RAs with an anthropomorphic interface, we expect users to rely on social affiliation when viewing online anthropomorphic RAs. This reasoning is explained by the CASA (Computer are Social Actors) paradigm that posits that people make *social inferences* about computer artifacts while using them (Reeves and Nass, 1996). Accordingly, three theories, namely, *similarity-attraction*, *homophily*, and *social identity*, have been used to justify the role of ethnicity and gender in the adoption and use of online RAs (Qiu and Benbasat, 2010).

First, similarity attraction theory (Byrne, 1971) posits that a user's perception of similarity with another person would result in the person's more positive overall assessment. According to the tenets of similarity attraction theory, the higher the similarity in with a person's demographic characteristics, such as ethnicity and gender, the higher the attraction toward that person will be.

Second, the theory of homophily, grounded in Lazarsfeld and Merton (1954), suggests that demographic similarity among people would result in a better communication and a more comfortable interaction.

Third, social identity theory (Tajfel and Turner, 1986) suggests that membership in a group confers a social identity that spawns a self-categorization process that exacerbates in-group similarities and worsens out-of-group differences (Turner, 1982). As people use these readily observable physical cues to classify other people as either "in-group" or "out-of-group" (Biernat and Vescio, 1993), ethnicity and gender are major issues involved in the self-categorization process (Messick and Mackie, 1989).

In sum, while ethnicity and gender are only two demographic characteristics that contribute to perceived similarity with a RA, they are two salient factors with key implications for the adoption and use of anthropomorphic RAs.

### ***Ethnicity and Gender Similarity***

Demographic cues, such as gender and ethnicity, are nonverbal cues that are both non-behavioral and low in individual control due to their inherent and relatively enduring nature (De Meuse, 1987). Therefore, similarity on these demographic variables can be identified with relative ease. In fact, there is strong evidence that the observable demographic characteristics of ethnicity and gender are the most important ones when evaluating another person (e.g., Ng et al., 2006; Qiu and Benbasat, 2010; Taylor et al., 1978).

Ethnicity is a strong demographic characteristic that contributes to similarity-attraction, homophily, social identity, self-categorization, and “in-group” favoritism. The literature has shown that ethnic similarity results in interpersonal attraction (Berscheid and Walster, 1978), desire to interact (Elsass and Graves, 1997), higher job ratings (De Meuse, 1987), and better performance evaluations (Tsui and O’Reilly, 1989). Hart et al. (2000) showed that ethnicity stimuli have a key role when subjects assess the faces of people from other ethnicities. Thus, we expect anthropomorphic RAs that match the user’s ethnicity to be evaluated more favorably by their users in terms of their social presence.

Gender is also another important demographic characteristic that is associated with positive “in-group” perceptions. For example, salespeople favored prospective customers of the same gender (Dwyer et al., 1998), while people had better interactions with their own gender in the workplace (Foley et al., 2006). Gender similarity also appears to be positively linked to a buyer-seller dyad’s relationship quality (Smith, 1998). Therefore, we expect gender similarity to also positively affect the evaluation of online RAs with an anthropomorphic interface in terms of social presence.

Taken together, we expect that, for RA users, both ethnic and gender similarity with a RA would lead to stronger perceptions of social presence (Qiu and Benbasat, 2009).

### ***Social Presence***

Social presence is used to capture the degree to which users assess the quality of the social connections with a RA. The concept of social presence refers to the feeling of being close to another person (Short et al., 1976), and it is often used to capture how people perceive the degree of intimacy and warmth of other people in distant locations (Biocca et al., 2003). Social presence is generally characterized as an instance of intrinsic motivation (Qiu and Benbasat, 2010), and it was shown to play an important role in the adoption of technologies outside the traditional workplace (e.g., Shang et al., 2005; Teo et al., 1999). Social presence was also extended to technological artifacts with anthropomorphic or human-like interfaces, such as humanoid agents, computer interfaces, and robots (Biocca, 1997; Nowak and Biocca, 2003). For example, Nass et al. (2000) showed that Korean users were more likely to perceive a RA that looked Korean to be more socially attractive than a RA that looked Caucasian, resulting in adopting the Korean RA. Extended to online RAs with an anthropomorphic interface, social presence is defined as the extent to which a user perceives to be psychologically close to a RA.

Qiu and Benbasat (2010) found that when users evaluate anthropomorphic RAs, they use social stereotypes similar to those used in traditional inter-personal communications. In their research, RAs that matched the user’s ethnicity (but not gender) were perceived to be more sociable to interact with than mismatched RAs. The authors found that RAs that matched the user’s ethnicity were perceived to have a higher sense of social presence than RAs that did not match the user’s demographics. Moreover, they showed that women are more likely to favorably evaluate a “matched” PRA than a “mismatched” one in terms of social presence. The IS literature has also examined the role of social presence in replicating the sense of connection between consumers and websites (Hassanein and Head, 2006). Social presence was also shown to build consumer’s trust (Gefen and Straub, 2003) and loyalty (Cyr et al., 2007; Kumar and Benbasat, 2006) in commercial websites and to encourage consumer purchases (Simon, 2001).

### ***Neural Correlates of Social Presence***

In terms of the neural correlates of social presence, drawing upon the neuroscience literature, it is expected that social presence to be associated with areas related to social inferences, namely the *anterior paracingulate cortex* (Rilling et al., 2004). The *anterior paracingulate cortex* is a brain area in the limbic system that is activated when a person engages in a social interaction (Walter et al., 2004) and predicting how others will act (McCabe et al., 2001). The neuroscience literature has linked the *anterior paracingulate cortex* as a key area of the “social brain” responsible for predicting the social behavior of others (Gallagher and Frith, 2003). Krueger et al. (2007) also showed the *anterior paracingulate cortex* to be activated when inferring another person’s future social intentions. The *anterior paracingulate cortex* is associated with social attachment behavior (Walter et al., 2004), and it was shown to predict a person’s engagement in a social relationship (Winston et al., 2002) and build social interactions (Dimoka, 2010a). Therefore, we propose that a user’s social presence of a RA that matches the user’s ethnicity and gender to activate the *anterior paracingulate cortex* relative to a RA that does not match her ethnicity and gender.

**H1: A user’s social presence toward a recommendation agent that matches the user’s ethnicity and gender is associated with higher activation in the *anterior paracingulate cortex* versus a recommendation agent that does not match the user’s ethnicity and gender.**

In general, it may be possible that RAs that do not match the user's ethnicity and gender to activate different brain areas relative to RAs that match the user's ethnicity and gender. In terms of social presence, this may be due to activation caused by negative feelings that arise from the lack of social presence. However, as social presence is the feeling of being close to another person (that is expected to increase if a RA matches a user's ethnicity and gender), we do not expect to observe any activation in the anterior paracingulate cortex when users do not perceive the sense of social presence with a RA that is dissimilar to them in terms of ethnicity and gender.

### Gender Differences in the Neural Correlates of Social Presence

The match versus mismatch effect of the RA's demographic cues (H1) is proposed to vary depending on whether the user's gender. Demographic match in terms of ethnicity and gender is a social cue, and we expect that women will pay more attention to social cues than men. Prior research has revealed that women and men are different in their communication abilities; women are generally more expressive and can convey meaning more clearly using non-verbal cues when interacting with others (e.g., Briton and Hall, 1995; Burgoon and Dillman, 1995; Spangler, 1995). Women are also generally better than men in decoding, understanding, and using nonverbal cues sent by others (Briton and Hall, 1995; LaFrance and Henley, 1994). Besides, women tend to pay more attention to social influences, while men focus more on the utilitarian aspects of the communication (Hofstede, 1980). Furthermore, it was found that female consumers are more motivated by social interactions than males (Swaminathan et al., 1999).

In addition to better decoding and using non-verbal cues in social interactions, women are also more inclined to act upon demographic cues. Favorable same-ethnicity bias was only observed in women supervisors when evaluating by female subordinates (Tsui and O'Reilly, 1989). Sociologists have also shown that women are more oriented to ethnic identity than men (e.g., Masuda et al, 1973; Ting-Toomey, 1981; Ullah, 1985). Qiu and Benbasat (2010) found that the matching-up effects of ethnicity with RAs are more significant among women than men.

Taken together, we expect women to be more sensitive to non-verbal cues conveyed by anthropomorphic RAs that match their ethnicity and gender. Therefore, we posit ethnicity and gender match effects to be significantly stronger for women than for men, and we anticipate that the proposed neural correlates of social presence in the *anterior paracingulate cortex* for RAs that match the user's ethnicity and gender to be more salient in women than in men:

**H2: The higher activation in the *anterior paracingulate cortex* associated with a user's social presence of a recommendation agent that matches the user's ethnicity and gender as compared to an agent that does not match the user's ethnicity and gender will be stronger for women as compared to men.**

## Research Methodology

### Experimental Design

A 2×2 *within-subject* factorial experimental design (subject-RA ethnicity × gender match/mismatch) was used (Table 1). Four simulated RAs were designed with two permutations of ethnicity (Caucasian, Asian) and gender (Male, Female). We chose Caucasian and Asians as these two ethnicities are consistent with the ethnicity literature (e.g., Ng et al., 2006). Accordingly, four groups of subjects were recruited whose gender and ethnicity were permuted to create four categories (Table 1) - ethnicity and gender match or mismatch (plus two partial mismatches, either ethnicity or gender mismatch).

The experimental design followed the guidelines for undertaking fMRI studies in the social sciences, as outlined by Dimoka (2010b), Huettel and Payne (2009), and Yoon et al. (2009). Interested readers are referred to these sources for more details on how to design fMRI experiments to localize the neural correlates of social constructs.

		Agent			
		Male		Female	
User		Asian	Caucasian	Asian	Caucasian
Male	Asian	AA-MM	AC-MM	AA-MF	AC-MF
	Caucasian	CA-MM	CC-MM	CA-MF	CC-MF
Female	Asian	AA-FM	AC-FM	AA-FF	AC-FF
	Caucasian	CA-FM	CC-FM	CA-FF	CC-FF

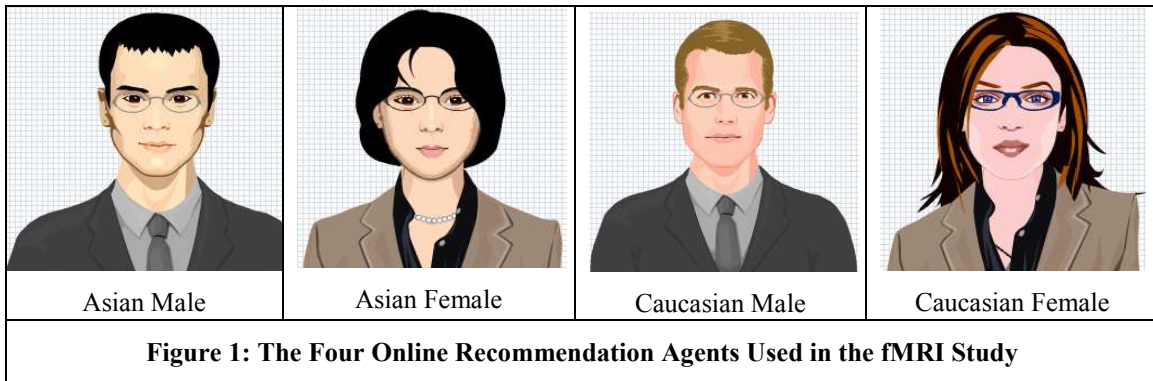
All users viewed *all RAs*, albeit the full match, partial mismatch, and full mismatch varied across users (Table 2).<sup>1</sup> While a between-subject design might have been possible, it will require four times as many subjects (n=96), which would be extremely difficult to conduct given the cost and time constraints of fMRI studies (Dimoka et al., 2010).

		<b>Gender</b>	
<b>Ethnicity</b>		<b>Match</b>	<b>Mismatch</b>
<b>Match</b>		<b>(Full Match)</b> AA-MM, CC-MM, AA-FF, CC-FF	<b>(Ethnicity Match – Gender Mismatch)</b> AA-FM, CC-FM, AA-MF, CC-MF
<b>Mismatch</b>		<b>(Ethnicity Mismatch – Gender Match)</b> CA-MM, AC-MM, CA-FF, AC-FF	<b>(Full Mismatch)</b> CA-FM, AC-FM, CA-MF, AC-MF

Based on Tables 1 and 2, the study first aims to study the effects of perceived similarity in terms of ethnicity and gender (full) match versus full mismatch, and second it aims to *explore* how partial match and mismatch may be different across ethnicity and gender.

**Design of Experimental Stimuli**

The RA system was adapted from Wang and Benbasat (2007) and the four anthropomorphic RA interface with salient ethnic and gender characteristics (Asian female, Asian male, Caucasian female, Caucasian male) (Figure 1) were selected after several pretests (Qiu and Benbasat, 2010).



The RA profiles were designed with Oddcast Sitepal software that provides a wide-array of characters that can be modified in terms of their physical appearance. The screen layout of the RAs was designed to simulate actual commercial RAs (Figure 1). The pre-tests showed that *all* of the subjects correctly identified the RA’s ethnicity and gender, and they were no significant differences among their perceived physical attractiveness and professionalism.

**Experimental Procedures**

An fMRI experiment was conducted in which the brains of 24 right-handed subjects were scanned. The number of subjects (n=24) was chosen to ensure adequate power of analysis (80%) for statistically-significant brain activations at a threshold of p<.05 (Desmond and Glover, 2002). The 24 subjects (6 Caucasian males, 6 Asian males, 6 Caucasian females, and 6 Asian females) who were pre-screened for fMRI safety (no medical implants, no metal

<sup>1</sup> Since ethnicity and gender match and mismatch is based on the association between the subjects with the RAs, the RA that is matched for certain subjects could be mismatched for others. This counter-balanced design gives control of any systematic differences that may exist among the four RAs, and it also allows us to explore how different subjects may differentially perceive ethnicity and gender match and mismatch.

objects, no physiological problems) participated in the fMRI study for \$35 compensation. Subjects were recruited from the population of the metropolitan area of a major US university using an open flyer for an fMRI study. The fMRI protocol and ad were reviewed and approved by the University's Institutional Review Board.

To elicit brain activation in the brain areas associated with social presence, measurement items in the form of psychometric Likert-type scales were used, following Dimoka (2010b). We used existing scales for social presence (Gefen and Straub, 2003), with minor changes in wording, as shown in Table 3.

<b>Table 3. Measurement Items for Social Presence</b>	
1.	I felt a sense of <u>human contact</u> in this recommendation agent.
2.	I felt a sense of <u>personalness</u> in this recommendation agent.
3.	I felt a sense of <u>human warmth</u> in this recommendation agent.
4.	I felt a sense of <u>sociability</u> in this recommendation agent.
5.	I felt a sense of <u>human sensitivity</u> in this recommendation agent.
6.	I felt a sense of <u>personal touch</u> in this recommendation agent.
7.	I felt a sense of ' <u>being together</u> ' with this recommendation agent.
8.	I felt a sense of <u>human kindness</u> in this recommendation agent.
9.	I felt a sense of <u>human warmth</u> in this recommendation agent.
10.	I felt a sense of <u>human connection</u> in this recommendation agent.

Following the suggestions of integrating fMRI and behavioral data (Huettel and Payne, 2009; Yoon *et al.*, 2009), to refine the experimental tasks and stimuli for the fMRI study, a behavioral lab experiment with 190 students that spanned the four demographic groups was conducted as a pretest. The fMRI design, experimental procedures, and measurement items were calibrated and refined with the behavioral study. The behavioral study replicated the fMRI design besides observing the subjects' brain responses in the fMRI scanner. Because the fMRI experiment would also collect behavioral responses, it would be possible to compare those data with the data from a traditional lab experiment to ensure that the behavioral data do not differ across studies and they are not biased by the constraints of the fMRI scanner, thus inferring external validity.

### Before the fMRI Session

Subjects were asked to work with each of the four RAs to get information about a digital camera for themselves. Digital cameras were chosen as the focal product that the RAs gave recommendation because of the complexity of their characteristics, the large number of alternative models, and the short lifespan of each product generation. Subjects simultaneously viewed all four RAs at the top of the screen who asked questions about digital cameras (Figure 2). Subjects were asked to provide their preferences to each question associated with a camera characteristic posed by all four RAs and to rate the importance level of each attribute in their answer. The questions did not come from any single RA but jointly from all four RAs. If subjects wanted to know more about a product characteristic, they could click the 'About This Question' button to get additional information. To make the experiment as realistic as possible, subjects were told that they have to evaluate, comment, and act upon the advice of these four PRAs to purchase a digital camera after the experiment. After subjects responded to the 10 questions, they were told that each of the four RAs would recommend them its best choice for them (that would be revealed during the fMRI session). For realism, subjects also selected one of three price ranges, and the RA's choices were within this price range.

To minimize any differences across the RAs (besides their ethnicity and gender), the recommended digital cameras of all RAs were virtually *identical* in terms of basic characteristics (e.g., price, resolution, zoom, size, and shape). We slightly modified these characteristics (e.g., picture and model number) to appear that the four options presented by each RA are different. Between-subjects experimental pretests revealed that subjects could not distinguish among the four digital cameras, and their evaluations and intentions to purchase each of the four digital cameras were not statistically across digital cameras. For added realism, subjects initially saw three digital cameras from each RA



(which were also virtually identical besides the model number) followed by each RA's top choice, which was clearly superior in terms of all characteristics relative to the other two options.<sup>2</sup>

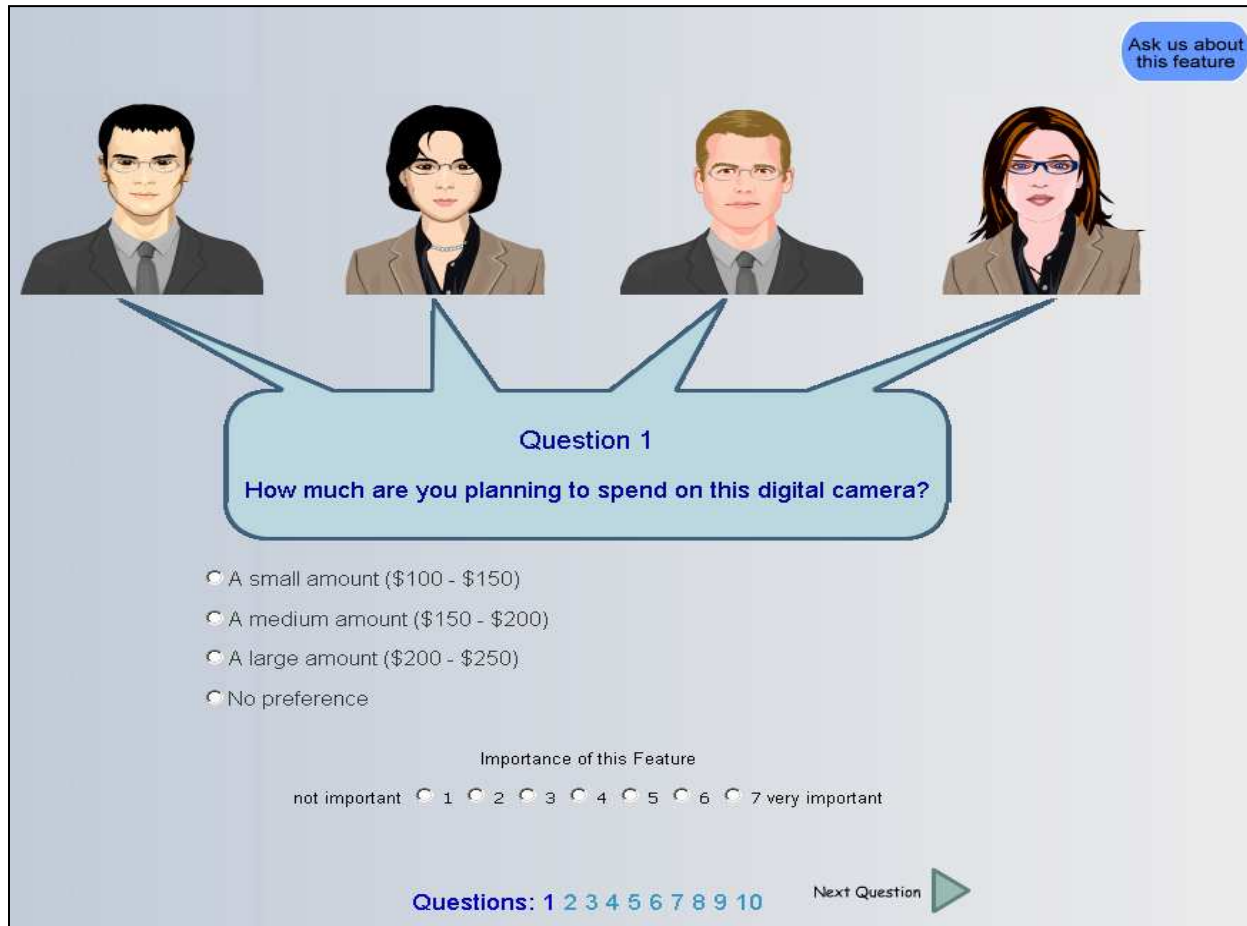
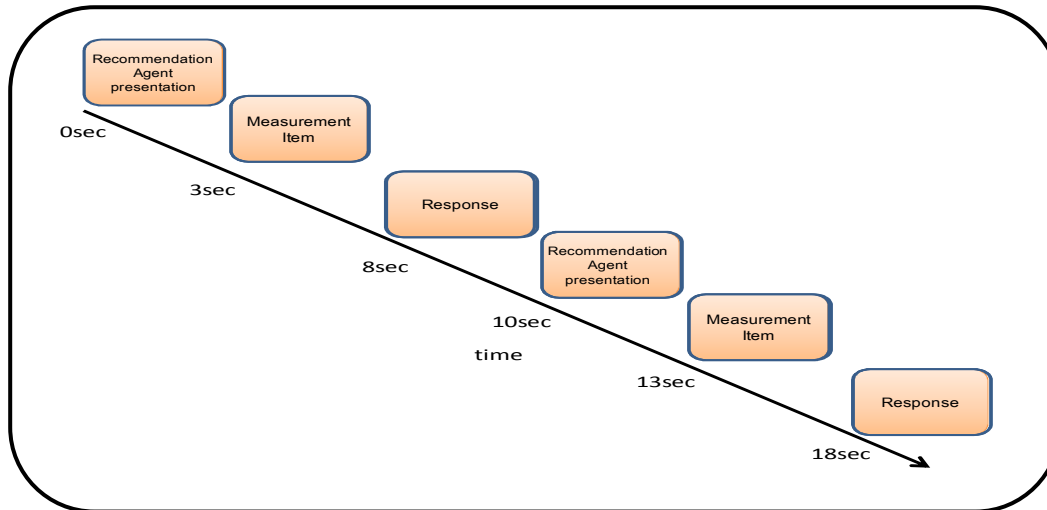


Figure 2. Screenshot of the Recommendation Agent Interface

### During the fMRI Session

Subjects then entered the fMRI scanner lying comfortably on their back. Visual stimuli (Figure 3) were projected to them through fiber-optic goggles connected to a computer. First, one randomly-selected PRA was presented together with a randomly-selected measurement item for a randomly-selected construct for the same focal PRA. Each stimulus was shown for 5 seconds without the scale, which was shown to be ample time for subjects to read and process (Dimoka, 2010a). Then, the 7-point Likert-type scale appeared, and subjects selected their choice by depressing one of the seven buttons using a fiber-optic mouse they held with their right hand. Subjects had unlimited time to make their choice, but the actual time they took in practice was about 2-3 seconds. After clicking on their choice, they were shown a new randomly-selected RA followed by a randomly-selected measurement item. This procedure was repeated for all RAs and measurement items, as shown in Figure 3.

<sup>2</sup> Besides price that was selected by the subject and used in the RA's recommendation, all other characteristics were fixed irrespective of the subjects' posted preferences. This is to ensure that all subjects saw an identical set of cameras to avoid variations across subjects due to looking at different cameras. No differences were observed across subjects who selected a different price range and were shown a corresponding digital camera within their chosen price range. Despite the fact that the recommended digital cameras were the same across all subjects and did not follow the subjects' stated preferences, none of the subjects raised concerns that the recommended cameras were unacceptable to them. Besides, we did not observe any behavioral or neurological differences across subjects due to the fact that the recommended cameras differed from their posted preferences.



**Figure 3. Graphical Description of the fMRI Study and Presentation of Stimuli**

The technical details associated with the fMRI data analysis procedures are reported in Table 4 and Appendix A. Interested readers are encouraged to review primers on how to conduct fMRI studies (e.g., Dimoka, 2009).

**Table 4. fMRI 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=21cm; 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 = 2s; 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 to compensate for delays due to acquisition time differences among slices during sequential imaging. 3-D automated image registration routines (six-parameter rigid body, sinc interpolation; second order adjustment for movement) were 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 embedded SPM5 normalization procedure (Ashburner and Friston, 1999). 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 study's contrasts were modeled with a canonical hemodynamic response function (hrf). Contrast maps were obtained through linear contrasts of all event types. The brain images were first analyzed for each subject separately. Then, second-level one-sample t-tests were used on the aggregate data to create random-effect group analyses for all constructs across all RAs. Group-level random effects analyses for main effects were accomplished by entering whole brain contrasts into one-sample t-tests. For each condition at the group level, Statistical Parametric Maps (SPMs) were generated with the z-value (which correspond to the unit normal distribution that renders the same p-values as the t-statistic in SPM) of each voxel (3D pixel) that exceeded a  $p < .05$  threshold. For the group (second) level analysis, Region of Interest (ROI) analysis was implemented, which involves defining a particular area of interest in the brain within which to make localized statistical analyses. 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.

#### After the fMRI Session

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

## Results

The analysis of the fMRI data was performed with SPM8 freeware. Whole-brain 3Tesla fMRI data were acquired in a time-series to provide contiguous 5mm thick brain slices allowing subjects to respond to the measurement items of social presence (Table 3) with a gap of about 10 seconds between two stimuli (measurement items). All brain activations were obtained during the latter part of the 5-second period where the subjects were reading each measurement item (before posting their response) to minimize confounds (e.g., visual stimuli, hand movement) when responding to the measurement item and assure temporal separation between the brain activity while reading the measurement item and the response on the Likert-type scale, following the method outlined by Dimoka (2010b).

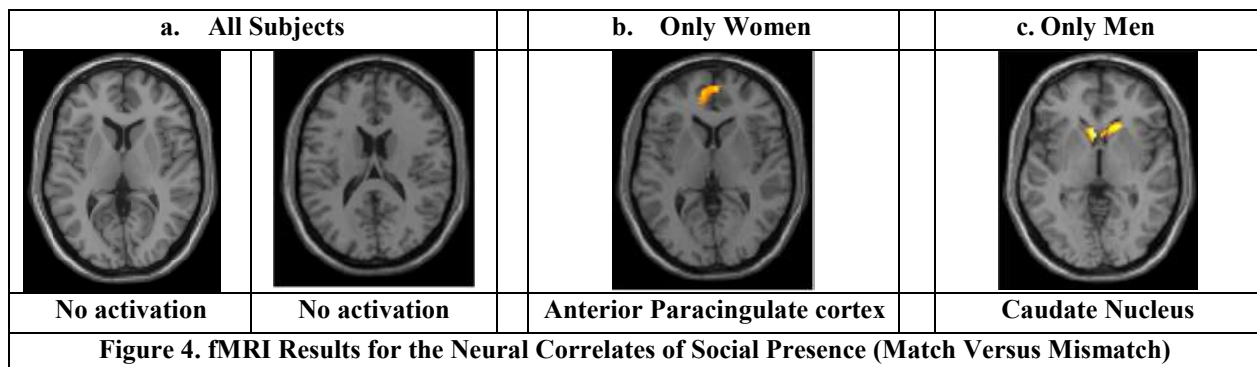
### Design of Contrasts

The first stage of the analysis aimed at identifying the neural correlates of social presence when comparing “matched” and “mismatched” RAs. The analysis was undertaken by contrasting the brain activations of social presence for the ethnicity and gender matched PRA relative to the mismatched PRA. The contrast between the “match” and “mismatch” image reflects the *difference* in brain activation due to the measurement item when responding for a RA that matches versus a RA that does not match the subject’s ethnicity and gender. Moreover, from the opposite perspective, the ‘mismatched’ versus ‘matched’ contrast reflects the difference in brain activity when responding to the measurement items about a RA that does not match the subject’s ethnicity and gender versus a RA that matches the subject’s ethnicity and gender. Because it is not possible to observe negative brain activation when subtracting two brain images and we can only observe positive activation that exceeds a statistical threshold, the contrast between match and mismatch can be different from the contrast between mismatch and match. Finally, while not hypothesized, we also examined the contrasts between both ethnicity and gender (full) match or full mismatch with ethnicity match/mismatch and gender match/mismatch separately in an exploratory fashion.<sup>3</sup> These exploratory tests help specify whether there are differences between match and mismatch for either ethnicity or gender *separately* (and not their combination), and whether certain brain activations are specifically due to either ethnicity or gender differences (versus ethnicity and gender differences together).

### fMRI Results - Neural Correlates of Social Presence

#### Hypothesis Testing

To test H1, we compared the brain activations when subjects responded to social presence for the RAs who matched their ethnicity and gender (“matched” RAs) versus those who did not match their ethnicity and gender (“mismatched” RAs) (Figure 4). While no significant activation in the anterior paracingulate cortex was observed for all subjects (Figure 4a), there was only significant activation for the female sample ( $z=1.84$ ,  $p<.05$ ) (Figure 4b), but not for the male sample (Figure 4c), thus supporting H1 for women only. These results render support for H2.



<sup>3</sup> Exploratory analysis is an accepted norm in fMRI studies (e.g., Cunningham et al., 2004; King-Casas et al., 2005), and it is an important benefit of neuroimaging methods. In fact, it is not common to test explicit hypotheses regarding particular brain areas. This is because a natural, data-driven approach is often preferred.

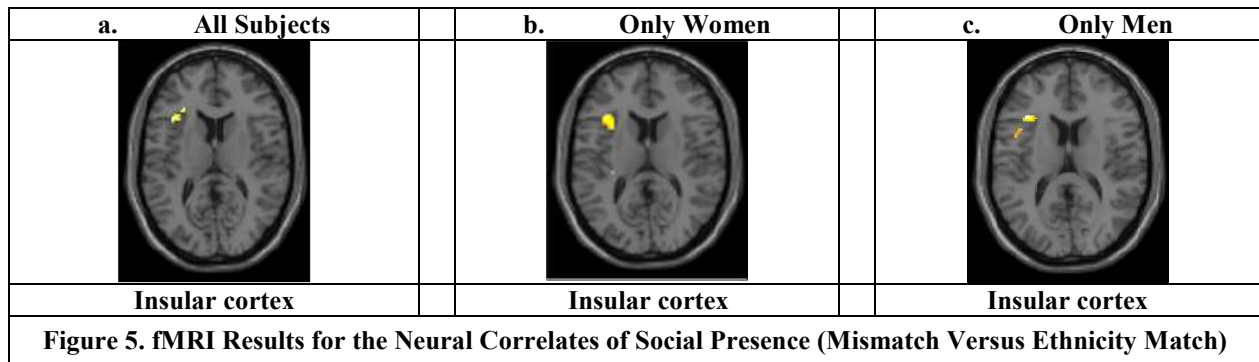
**Exploratory Analysis**

We also conducted the analysis for ethnicity match and gender match separately in an exploratory fashion. There was no significant activation for either ethnicity match or gender match, neither for all subjects, women, or men. This implies that the combination of ethnicity and gender (full) match is necessary to spawn significant activation in the anterior paracingulate cortex for women (Figure 4b).

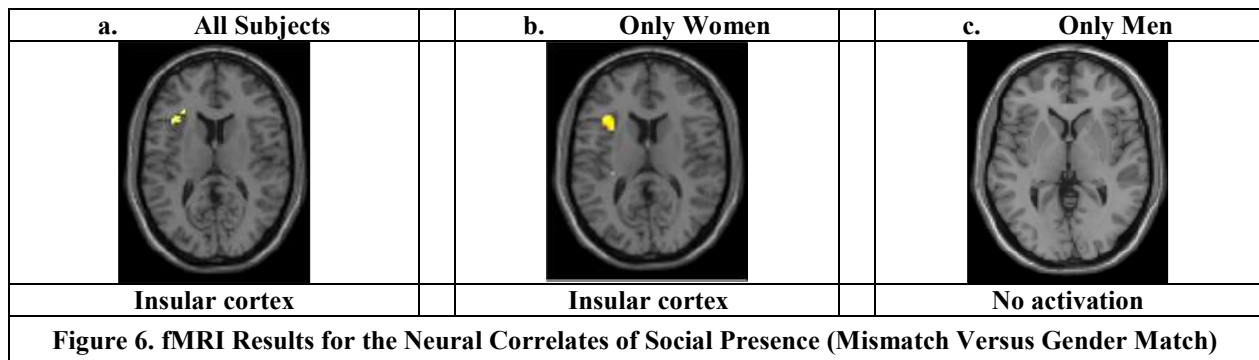
While *not* hypothesized, a significant brain activation was identified in the *caudate nucleus* only for the male sample ( $z=2.37, p<.05$ ) (Figure 4c), a brain area associated with anticipated utility and mutual rewards (e.g., Hsu et al., 2005; Knutson *et al.*, 2001) from expected cooperation and reciprocity (King-Casas et al., 2005; Rilling et al., 2008). This finding is also consistent with Singer et al. (2006) who found that men’s responses are shaped by evaluating the utility to be obtained by other people’s social behavior and Hofstede (1980) that men focus more on the utilitarian aspects of the communication.

A significant activation in the caudate nucleus in men (Figure 4c) was also observed in the ethnicity match contrast ( $z=2.13, p<.05$ ) (omitted for brevity). However, there was no significant activation in the gender match versus full mismatch contrast, implying that the observed activation for full match was largely due to ethnicity match for men.

Our theory did not expect any activation for the mismatch versus match comparison because lack of social presence (which is expected in the mismatched case due to lack of similarity) was not expected to spawn any brain activation. The fMRI results confirmed this expectation because no significant activation was observed for social presence, neither for all subjects, women, or men. However, for the full mismatch versus ethnicity match, there was significant brain activation in the insular cortex for all subjects ( $z=2.03, p<.05$ ) (Figure 5a), for women ( $z=3.05, p<.01$ ) (Figure 5b), and a marginally significant activation for men ( $z=2.06, p<.10$ ) (Figure 5c).



Also, there was significant activation in the insular cortex for the full mismatch Vs. gender match in all subjects ( $z=2.76, p<.05$ ) (Figure 6a) and women ( $z=3.79, p<.01$ ) (Figure 6b), but not in men (Figure 6c).



Finally, it is important to note that there was no significant activation in the *nucleus accumbens*, an area associated with attractive faces (Aharon et al., 2001). This implies that the RA’s relative attractiveness did *not* spawn any differential brain activation, validating our pretest that all RA’s were equally attractive. Besides, aesthetic evaluation was shown to be distinct from rewards evaluation (Aharon et al., 2001), implying that our results are not driven by aesthetic evaluation. Also, besides breaking down the analysis by the user’s gender, we also performed the analysis by the user’s ethnicity. However, no differences were observed when comparing Caucasian and Asian subjects.

### Comparison with Behavioral Results

Given that the fMRI results were obtained when subjects were responding to psychometric measurement items for social presence on a 7-point Likert-type scales (Table 3), it is possible to conduct an analysis of the behavioral data.

First, Table 5 presents the descriptive statistics for social presence. While there is a non-significant ( $p > .10$ ) difference between ethnicity and gender match ( $\mu = 3.91$ ) and mismatch ( $\mu = 3.71$ ) across all subjects, there is a significantly higher ( $p < .05$ ) level of social presence for matched ( $\mu = 4.37$ ) than mismatched RAs ( $\mu = 3.40$ ) in *women*, while there is borderline significantly higher ( $p < .10$ ) level of social presence for mismatched ( $\mu = 3.92$ ) than matched RAs ( $\mu = 3.44$ ) in *men*. These results are consistent with the fMRI results (Figure 4) that show significant gender differences in terms of the brain activations in the anterior paracingulate cortex for women (Figure 4b) and the caudate nucleus for men (Figure 4c), while there are no significant brain activations across all subjects (Figure 4a).

Table 5. Means for Ethnicity and Gender Match versus Mismatch across Gender		
	Social Presence	
Ethnicity and Gender (Full) Match	3.91	
Ethnicity and Gender (Full) Mismatch	3.71	
Split by User's Gender	Women	Men
Ethnicity and Gender (Full) Match	4.37	3.44
Ethnicity and Gender (Full) Mismatch	3.40	3.92

Second, Table 6 reports the 2 (full match versus mismatch)  $\times$  2 (Male, Female) ANOVA was then used to examine whether there is a difference between ethnicity and gender (full) match and mismatch for social presence. There were no main effects due to ethnicity and gender (full) match or user's gender, but there was a marginally significant interaction effect for social presence, consistent with the fMRI results that showed stark differences across genders in terms of both the location and level of the observed brain activations (Figure 4).

Table 6. ANOVA Results for Social Presence	
	Social Presence
Ethnicity and Gender (Full) Match	$F = .485^{NS}$
User's Gender	$F = .592^{NS}$
Ethnicity and Gender Match * User's Gender	$F = 4.248 (p = .053)$

Third, while the behavioral results do not reveal any negative perceptions from the lack of social presence when dealing with RAs that do not match either the user's ethnicity or gender (Table 6), the fMRI results show an activation in the insular cortex (an area associated with the fear of loss) (Wicker et al., 2003) for ethnicity and gender mismatch (Figures 5 and 6). The brain data can also specify whether the fear of loss due to the lack of social presence are due to ethnicity (Figure 5) or gender (Figure 6) mismatch across women and men, while the behavioral data cannot infer whether ethnicity or gender mismatch causes any differences in social presence.

Finally, these reported behavioral results during the fMRI setting were similar to those of the behavioral pretest that was conducted prior to the fMRI study. This implies that the constrained fMRI context did not bias the subjects' behavioral responses, testifying to the external and ecological validity of the fMRI study, at least relative to a traditional behavioral study.

## Discussion

### *Key Findings*

This study has three major findings: First, although there were no *main* effects associated with social presence in the *anterior paracingulate cortex*, and H1 was not supported for the whole sample, but it was supported only for the female sample. Accordingly, the results supported the *interaction* hypotheses for user's gender, thus supporting H2. Second, the behavioral results are largely consistent with the fMRI results in that the only significant effects are associated with the RA's ethnicity and gender (full) match X user's gender interactions, but there were no main effects for full match versus full mismatch. Thus, both the behavioral and fMRI data indicate that the interaction effects are due to the fact that ethnicity and gender match is more relevant for women than for men. Third, the exploratory (non-hypothesized) investigations reveal some interesting brain activations (caudate nucleus) in men. Finally, the benefits of conducting fMRI analyses over having behavioral data only is that we are able to capture the neural correlates of social presence, thus giving us a neurological explanation as to why different anthropomorphic RAs that match the user's ethnicity and gender are more likely to be adopted and used differently across genders.

### *Implications for Theory Development*

The role of similarity theories in the design of anthropomorphic RAs has been recently discussed in the IS literature, initiated by the work of Al-Natour, Benbasat, and Cenfetelli (2006; 2008). They theoretically argued and empirically showed that a behavioral and personality match between an advice giving system (e.g., RA) and its users has a beneficial effect on key variables that influence the adoption and use of RAs. Qiu and Benbasat (2010) proposed demographic (ethnicity and gender) match as another type of similarity that is important in the design of RAs. Accordingly, this study extends this literature specifically for social presence by providing a complementary set of brain data derived with fMRI tools, which can help extend similarity theory as they apply to the design of RAs.

This study's *first* key contribution has been to theoretically propose and empirically demonstrate with brain data the differences between women and men in terms of the neural correlates of social presence – which was associated with the adoption and use of PRAs (Qiu and Benbasat, 2010). The brain activations between women and men are starkly different, as it is testified by the main effects across all subjects where no significant activation was observed when pooling two starkly different samples (Figure 4a). While the behavioral data also statistically infer interaction effects due to gender differences (Table 6), the brain data specify the neurological differences between women (Figure 4b) and men (Figure 4c). Although in women there is only activation in the anterior paracingulate cortex that is associated with social inferences and social attachment, in men there is only activation in the brain's reward areas. This implies that the behavioral differences between women and men can be explained by the more pervasive activity that occurs in women's "social" brain versus the men's "utilitarian" brain that is activated when dealing with RAs that match their ethnicity and gender. Based on the observed brain activations, women engage in a process of social interaction (anterior paracingulate cortex) that arises from their interaction with RAs, while men focus on potential rewards (caudate nucleus) when matched RAs give the sense of social presence to them. In sum, the observed behavioral gender differences (Tables 5 and 6) can be explained by the complex underlying differences in the brain activations across genders (Figure 4). Therefore, we need to extend similarity theory as it applies to RA use by adding the user's gender as a moderator and explaining the neurological basis for these observed differences.

The study's *second* key contribution is to show that both ethnicity and gender match are necessary to understand why users prefer RAs that match their demographics. While the literature has argued that ethnicity is a more important attribute than gender (e.g., Cowell et al. 2005; Cunningham et al. 2004; Taynor and Deaux, 1973), our results suggest that both demographic characteristics are actually needed in terms of the observed brain activations. Similarly, in terms of the brain activations in the insular cortex when dealing with mismatched RAs, the results suggest that both ethnicity (Figure 5) and gender (Figure 6) mismatch can separately elicit this brain activation. The only stronger effect of ethnicity is present in the male sample where ethnicity mismatch does elicit brain activation in the insular cortex (Figure 5c), while gender mismatch does not elicit a significant brain activation (Figure 6c).

A *third* key contribution of this study is to provide an understanding of *why* ethnicity and gender match is important across genders. The fMRI results help us understand how social presence is differently mapped into the brains of women and men. While women emphasize social interaction, attachment, and relationship when assessing RAs that match their ethnicity and gender (as suggested by their activation in the anterior paracingulate cortex), men

emphasize utility when assessing RAs that are similar to them (as suggested by the observed brain activation in the caudate nucleus). This is consistent with Gefen and Straub (1997) who showed that women perceive higher social presence from IT artifacts (e-mail) than men. However, while the behavioral explanation in the literature was that women are generally more emotionally expressive and can convey their emotions easier than men (Briton and Hall, 1995; Burgoon and Dillman, 1995; Spangler, 1995), the fMRI data suggest that it is not that men cannot verbally express or behaviorally convey their emotions but rather that men do not elicit brain activations in the same areas as women. In contrast, men elicit activations in different brain areas associated with utilitarian considerations (caudate nucleus), consistent with the literature that men are more utility-oriented (e.g., Minton and Schneider 1980).

A *fourth* key contribution of this study is to reveal from our exploratory investigations that both women and men show aversion toward RAs that do not match either their ethnicity or their gender (or both), as suggested by the brain activation in the insular cortex (e.g., Sanfey *et al.*, 2003; Rilling *et al.*, 2008). The insular cortex is a primary sensory brain area that is typically activated by negative information (Wicker *et al.*, 2003), and it has been associated with the fear and anticipation of losses (Preuschoff *et al.*, 2008). While our hypotheses only suggested “positive” brain areas to be activated (anterior paracingulate cortex responsible for social inferences) in response to social presence from matched RAs, there was also significant activation in the insular cortex from RAs that did not match either the user’s ethnicity or the user’s gender. While social presence denotes an intrinsic motivation by being psychologically close to a person (or anthropomorphic RA), perhaps the lack of social presence may spawn negative reactions, as reflected in the insular cortex activation. Besides, it may be that social presence is not captured as a continuum from zero to a large degree, as traditional behavioral studies would imply, but there is a “negative” form of social presence caused by entities, such as mismatched RAs, which are perceived to render a negative perception. Thus, the fMRI results may uncover some interesting aspects of social presence. These unexpected fMRI results also attest to the ability of fMRI studies to identify “hidden” aspects of existing constructs (Dimoka *et al.*, 2010) that existing behavioral methods may not be able to uncover.

### ***Implications for the Design of Online Recommendation Agents***

For practitioners, this research calls for more attention to demographic factors - ethnicity and gender - in the design of anthropomorphic RAs. We recommend that designers of online RAs provide users with an anthropomorphic RA that matches their ethnicity and gender to improve their evaluations. While it is generally costly to offer traditional salespeople that match the customer’s ethnicity and gender (Jones *et al.*, 1998), IT artifacts in the form of online RAs can be easily designed to match each consumer’s ethnicity and gender. Although some managers may doubt that the cost for designing multiple anthropomorphic interfaces is unwarranted, the findings of our study suggest that users, particularly women, are influenced by the ethnicity and gender matched RAs. Compared with other more dynamic and subtle nonverbal behaviors, such as facial expressions or body gestures, the demographic characteristics of an anthropomorphic RA are inherently static and thus relatively easy and cheap to design. Based on the information collected from users’ demographics, it is possible for commercial websites to use the customers’ demographic information and present the optimal embodiment of an online anthropomorphic RA. At the very least, the website should provide different types of online RAs that vary in their demographic characteristics and allow consumers to pick the RA’s desired ethnicity and gender.

### ***Implications for HCI Research***

While fMRI methods have been used extensively in psychology, economics, and marketing with great benefits, it is only recently that they have been proposed for use in IS and HCI studies (Dimoka *et al.*, 2010). To our knowledge, this is the first HCI study in IS research that demonstrates how research that can be conducted utilizing traditional HCI laboratory experiments can be transformed into a neuroimaging (fMRI) study. Therefore, this study adds value to the HCI literature in several ways:

First, given the lack of HCI fMRI studies in IS research, it is a good exemplar of how to conduct such a study, illustrating both the challenges and benefits of fMRI studies. It also indicates the specialized knowledge and procedures needed to conduct an fMRI study to inform HCI phenomena, especially the kind of expertise required to interpret fMRI data and integrate with behavioral data. HCI researchers have for long been interested in using methods that open the “black box” in order to understand how and why different independent variables influence design outcomes (Minnery and Fine, 2009). The fMRI method is a key addition to the portfolio of such methods.



Second, the data gathered can offer insights and depth that go far beyond what the data and analyses from a typical HCI study would reveal as discussed in the *Implications for Theory Development* section above. While some of these findings are also supported by the corresponding behavioral data, the higher explanatory power of fMRI data, both in terms of describing the neural correlates of traditional IS constructs and the additional insight gained from its exploratory capabilities, is significantly higher.

Third, the data reveal some interesting facts about *social presence*, a commonly-used construct in the HCI literature, particularly in the context of how human beings interact with online RAs. For example, the literature has viewed social presence as being generated by a similar entity a desirable perception that would lead someone interact more closely with another party (web store) or a software aid (recommendation agents). However, fMRI data indicate that the strong negative reactions engendered by dissimilar entities with which we interact may be as, if not more, powerful force that justifies the design of similar human-computer interfaces.

### ***Limitations and Suggestions for Future Research***

Despite the potential of complementary fMRI data to shed light on the neurological processes associated with PRAs, fMRI studies have limitations in terms of the constrained nature of the fMRI scanner, the cost of the fMRI experiments, and the complexity of the fMRI data analysis. Future research could examine whether the idiosyncratic nature of the fMRI scanner raises concerns about external validity relative to traditional behavioral studies.

Besides social presence, there are other constructs that influence the adoption and use of RAs whose neural correlates may offer further insights on the neurological processes involved in the assessment of RAs and potential gender differences. For example, enjoyment was shown to influence the adoption of RAs (Qiu and Benbasat, 2009). Future research could examine the neural correlates of other constructs that may influence the adoption of RAs.

Also, more studies are needed to study the impacts of other non-behavioral cues that might be implemented in RAs. As proposed by De Meuse's (1987) model of nonverbal behavior, demographic and physical appearance features of a RA, including its age, facial and bodily attractiveness, clothing and accessories, voice characteristics and accent, could influence perceived sociability, credibility, likeability, or usefulness. Results from such research stream could provide practitioners with more specific design guidelines for embodied RAs used in online shopping environments.

Researchers could also get more insights into how people react to virtual characters in online shopping environments through the manipulations of other cues of a RA's social realism. In addition, the findings of our study can be applied to other non-shopping environments, such as distance learning and e-government, where the use of demographic matching RAs might also be preferred by users.

The fMRI study used the Likert-type scales of social presence as stimuli to induce brain activation (Dimoka, 2010b). Still, there are other means to induce brain activation, such as asking subjects to interact with RAs and select the one they prefer to transact with. Although the fMRI data do not suffer from these biases in the same way as self-reports, future research could have a more objective dependent variable that does not depend on self-reports.

### **Conclusion**

Opening the "black box" of the human brain is proposed to have the potential to enhance both HCI research in particular and the IS discipline in general, as this study attests in the context of technology-mediated environments where the social presence of online anthropomorphic recommendation agents is an important antecedent of their acceptance and use. Several new insights on the nature of the human-computer interaction with online recommendation agents can emerge, such as the neural correlates of social presence in technology-mediated environments and interesting differences between women and men when interacting with recommendation agents.

In both the HCI area and also the IS research, fMRI data can complement existing behavioral and other sources of data to offer rich insights that cannot be readily obtained or inferred by self-reported data, such as issues pertaining to ethnicity and gender that subjects are unlikely to self-report due to social desirability bias or political correctness. This study aims to encourage neuroimaging studies in HCI research to explore the underlying nature of IS constructs by identifying their neural correlates, and we believe fMRI studies can provide the next big jump in HCI research toward better understanding how humans interact with computers in the form of online recommendation agents. Consequently, we seek to encourage future HCI research on examining the neural correlates of IS constructs toward uncovering interesting new insights that may not be readily available by existing methods and tools.



## **Appendix A. fMRI Technical Details**

### ***Designing the fMRI Protocol***

#### **Preparing the fMRI Protocol**

Before designing the fMRI protocol, it is advised that a classic behavioral study is executed to ensure that subjects perceive the experimental tasks, understand the manipulations, and perform the tasks correctly. The experimental protocol is modified for the fMRI context to allow a comparison between the data collected during the traditional behavioral experiment and the fMRI experiment, either with the same set of subjects (if needed to train subjects for the fMRI study) or a different one (to enable a between-subjects comparison). Also, the fMRI protocol must also include the procedures the subjects perform before the fMRI session.

#### **Experimental Tasks**

The fMRI protocol engages subjects in a set of experimental tasks that aim at manipulating particular processes while the corresponding brain activations are recorded with an fMRI scanner. Relative to traditional lab experiments, experimental tasks in fMRI studies must be simpler to enable a more straightforward link between the experimental tasks and the resulting brain activations. The experimental tasks are broken down into a set of experimental conditions that are intended to create adequate variation in the study's independent variables.

#### **Contrasts and Controls**

fMRI experiments are similar to traditional behavioral experiments that must assure that the observed measures (brain activations) are due to the experimental conditions and not due to confounding factors. fMRI protocols must have a contrast between either the experimental condition and a control or 'baseline' condition or between two experimental conditions (e.g., high and low). Also, since any task, such as moving a finger, seeing an image, or hearing a sound may spawn brain activity (e.g., motor, visual, and auditory cortex), it is necessary to create a contrast between the expected activation in the appropriate brain areas (due to the experimental condition) and all other confounding activations. Such confounding activations are problematic because they may raise the total level of brain activity and statistically suppress true brain activations. The fMRI protocol must thus contrast the control condition (which must be designed to invoke the exact same brain functions except the focal brain activity due to the experimental condition) from those invoked by the experimental condition, thus isolating brain activity only due to the experimental condition. In other words, it is necessary to cancel out or statistically "subtract" all brain activity not spawned by to the experimental condition, such as spurious motor, visual, and auditory activities.

#### **Number of Subjects**

The number of subjects must be chosen to ensure adequate power of analysis for obtaining statistically-significant brain activations, and there are sources to calculate the required number of subjects (Desmond and Glover, 2002). The required sample size for fMRI studies is typically lower than behavioral lab studies because fMRI protocols include repetition in the experimental design that raises the power of analysis.

#### **Procedures during fMRI Session**

During an fMRI session, subjects lay comfortably on their back within the MRI scanner. During approximately the first 5 minutes, anatomical (structural) images of the brain are acquired while subjects lay still and do not perform any tasks. The structural images serve both to provide a high resolution image of the brain's anatomy over which the fMRI data can be overlaid, and also to specify where the fMRI data should be collected. Functional data are then collected while subjects respond to the experimental stimuli, such as visual, auditory, or tactile stimuli while the fMRI scanner records the BOLD signal throughout the brain in approximately 2-second intervals. The behavioral responses during the fMRI session can also be used for further interpretation and comparison with the fMRI data.

## **fMRI Image Acquisition**

The first step is to describe the fMRI scanner in terms of manufacturer and field strength. The higher the magnet's field strength, the better the resolution of the fMRI image. To scan (or acquire fMRI images from) the whole brain, about 30 slices are needed, which are typically collected every 2-3 seconds (termed Repetition Time or TR), depending on the study's needs for temporal resolution. Depending on the format and length of the fMRI protocol, 500–1,500 functional brain images are collected, each one subdivided into small cubes called voxels (volumetric or 3D pixels). Voxels are typically 3–5mm, with 25,000–50,000 voxels required to cover the whole brain. Data from a single voxel over the course of an fMRI study constitute a time series of fMRI BOLD signals that correspond to 500-1,500 brain images. The fMRI scanner captures two types of images with distinct acquisition parameters; structural images for the brain's anatomical structure and functional images that show changes in the BOLD signal. These include the pulse sequence type (gradient/spin echo, EPI/spiral), matrix size, field of view (FOV), acquisitions (NEX), flip angle, echo time (TE), slice thickness, acquisition orientation (axial, sagittal, coronal, oblique), and order of acquisition of slices (sequential or interleaved).

## **Analyzing fMRI Data**

The analysis of fMRI data mainly aims to identify the localization and level of functional activation of the brain areas that are activated in response to the experimental stimuli specified by the fMRI protocol. The functional images are then analyzed to identify brain areas that are significantly more active during the experimental stimuli relative to the controls. The following steps must be followed when analyzing fMRI data, which are divided into the pre-processing of fMRI data and statistically analyzing fMRI data.

Before fMRI data are ready for statistical analysis, they must be pre-processed to remove noise, increase the signal-to-noise ratio, and allow comparisons among different anatomical brains across subjects. Pre-processing of fMRI data includes the following major steps. First, slice timing correction allows for since images (slices) within a single brain volume are obtained sequentially and not at exactly at the same time, slice timing correction is performed to compensate for delays associated with acquisition time differences among images during the sequential collections of functional images. Second, since subjects spend 30-45 minutes inside the fMRI scanner and some head movement is likely to occur that results in spatial changes in terms of where specific voxels correspond, accurate movement corrections are important in fMRI studies because even small movements may result in systematic effects, which could spawn false positive brain activations if accumulated over many images. Third, during the spatial co-registration process, the whole brain images must be realigned to each other because there may be systematic differences in the images across whole brain scans. Hence, the images must be aligned to each other by aligning all subsequent images of each brain volume to the first image of the brain volume. Moreover, the images in each whole brain image must be aligned to the first image of the brain volume. Fourth, since healthy brain tissue can generally be classified into three broad types using MRI images - grey matter, white matter, cerebrospinal fluid - segmentation is used to assign the probability that each voxel should belong to each tissue type based on combining the likelihood for belonging to that tissue type and the prior probability that is derived from prior probability maps derived from a large number of subjects. Fifth, since brains differ in size and shape, to compare brain activations across subjects, brains must be spatially normalized to a template (average) brain in order to account for structural differences in the subjects' brains. The so-called normalization refers to scaling the data to a standard template brain to allow inter-subject comparison. Finally, since functional anatomy (the location of brain functionality) may differ across subjects, the functional images must be smoothed to overcome spatial variance.

## **Performing fMRI Data Analysis**

fMRI data are usually analyzed at the individual voxel level in order to identify whether the time-series activation of individual voxels corresponds to the experimental condition relative to a control condition. The most common approach is a parametric univariate analysis implemented within the General Linear Model (GLM), which fits a reference hemodynamic response function (hrf) to the brain data. The statistical significance of any given voxel and its level of activation reveal the association with the experimental condition. After the analysis is conducted at each voxel, the value of each voxel is a statistical value (often expressed in t-values or z-values), which is displayed in a Statistical Parametric Map (SPM). Since there are thousands of voxels in the whole brain, there is a risk of Type I error due to the many statistical tests at each voxel. Correcting for multiple comparisons is important because a standard fMRI analysis includes computing separate statistical tests for each voxel using a Bonferroni correction.

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