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Social Neuroscience

ISSN: 1747-0919 (Print) 1747-0927 (Online) Journal homepage: http://www.tandfonline.com/loi/psns20

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To cite this article: Gayannée Kedia, Thomas Mussweiler, Ruth Adam, Anja Ischebeck, Niklas Ihssen & David E. J. Linden (2019) So pretty! The neural correlates of self-other vs familiar-other attractiveness comparisons, Social Neuroscience, 14:1, 41-52, DOI: 10.1080/17470919.2017.1397544

To link to this article: https://doi.org/10.1080/17470919.2017.1397544

SOCIAL NEUROSCIENCE
2019, VOL. 14, NO. 1, 41–52
https://doi.org/10.1080/17470919.2017.1397544

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So pretty! The neural correlates of self-other vs familiar-other attractiveness comparisons

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ABSTRACT

Previous research has demonstrated that comparing two persons activates a frontoparietal network associated with numbers and nonsocial magnitudes. However, it is unclear whether this network is also recruited by comparisons involving the self. Self-reflection engages self-serving motivations (e.g., the maintenance of a positive self-image) and is associated with specific brain structures, such as the medial prefrontal cortex (MPFC), the anterior insula (AI) and the anterior cingulate cortex (ACC). Self-other comparisons may thus rely on distinct neural activity. To clarify this question, we used fMRI and asked female participants to compare their own attractiveness (or the attractiveness of a familiar woman) to pictures of unknown women. Participants were slower for comparisons with targets whose attractiveness was similar to their own (or their familiar other). Yet although this behavioral result resembles the *distance effect* reported for nonsocial magnitudes, at the brain level, it was linked to the activity of the AI, the ACC and the MPFC. The effect of distance in these regions was stronger for self-other than familiar-other comparisons. We interpret these results in relation to previous literature in social psychology and social neuroscience.

ARTICLE HISTORY
Received 3 March 2017
Revised 9 October 2017
Published online 10 November 2017

KEYWORDS
Social comparison; attractiveness; self; insula; anterior cingulate cortex; fMRI

Introduction

Internet and Facebook are replete with motivational statements encouraging people to stop comparing themselves to others. Quotations attributed to Theodore Roosevelt – “Comparison is the thief of joy” – or Karl Lagerfeld – “Personality begins where comparison ends” – depict *social comparison* as a hindrance on the way to happiness. Yet, it is not so easy to refrain from comparing oneself. Social comparisons are deeply rooted in the human psyche. Consciously or not, people measure their opinions, abilities or possessions in relation to those of others (Mussweiler, Rüter, & Epstude, 2004). In fact, contrary to the common view, this drive also entails beneficial effects. Comparing oneself to similar superior others is, notably, one of the motors of self-improvement as it can foster motivation to equal or even surpass the upward standard (Lockwood & Kunda, 1997; Wheeler, 1966). Moreover, people often engage in downward comparisons to feel better about themselves, especially when they feel threatened in their self-esteem (Wills, 1981). Failures and negative events appear under a more positive light when put in contrast to others who are worse off (Wood, Taylor, & Lichtman, 1985). In general, people engage in social comparison as a method of self-evaluation (Festinger, 1954; Kahneman & Miller, 1986; Mussweiler, 2003). When it comes to judging oneself or assessing one’s current situation, there is often no objective, standardized reference; rather, people perform such evaluations in relation to a given context. In the present article, we investigated the neural mechanisms underlying this core cognitive process and relied on an original paradigm inspired by research on numerical cognition and magnitude processing.

Neuroimaging studies on comparisons of numbers and simple physical dimensions have revealed a *frontoparietal network* dedicated to the representation and processing of *magnitudes* (Cohen Kadosh & Walsh, 2009; Nieder & Dehaene, 2009). Activity in this network during comparison is modulated by the distance between the two magnitudes: The closer the magnitudes (e.g., 2 and 3), the more difficult to compare (i.e., slower RTs and decreased accuracy) and the stronger the activity of the frontoparietal network (Cohen Kadosh et al., 2005). This network has been associated with the processing of several simple magnitudes such

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Supplemental data for this article can be accessed here.

as numbers, size or luminance. Research in social neuroscience has more recently suggested that it is recruited when comparing social targets.

Indeed, it seems that the cognitive processes underlying person comparisons are also modulated by the distance between the two targets and engage similar brain mechanisms as the comparison of nonsocial magnitudes. Previous studies have reported a distance effect for comparisons of two persons' height, attractiveness, or hierarchical status that overlaps with comparisons of nonsocial targets (e.g., numbers, cars, or dogs) in the intraparietal sulcus (IPS) as well as in the dorsolateral prefrontal cortex (DLPFC), the medial prefrontal cortex (MPFC) and the cerebellum (Chiao et al., 2009; Kedia, Mussweiler, Mullins, & Linden, 2014). This overlap suggests the existence of a common comparative neural mechanism for different kinds of magnitudes, including social characteristics (Kedia, Mussweiler, & Linden, 2014; Ohmann, Stahl, Mussweiler, & Kedia, 2016). However, so far it has remained unclear whether this network is also recruited by comparisons involving the self.

Numerous behavioral and neuroimaging studies have demonstrated that self-reflection is subjected to specific processing (Northoff, Qin, & Feinberg, 2011). Self-evaluations entail a stronger emotional and motivational component than the assessment of other people's characteristics (Shepperd, Malone, & Sweeny, 2008). At the behavioral level, they are performed faster and memorized better than evaluations that only involve others (Rogers, Kuiper, & Kirker, 1977). At the brain level, self-referential tasks elicit specific patterns of activation. A meta-analysis by Araujo, Kaplan, and Damasio (2013) reports that the evaluation of self-traits recruits cortical midline structures, such as the medial prefrontal cortex (MPFC) and the anterior cingulate cortex (ACC), as well as the anterior insula (AI), and the superior frontal gyrus (SFG) to a greater extent than the evaluation of other-traits. The authors propose that these regions contribute to the retrieval of autobiographical memories as well as the somatic and perceptual representations associated with these memories (Gu, Hof, Friston, & Fan, 2013; Modinos, Ormel, & Aleman, 2009; Northoff et al., 2006).

Recent fMRI studies suggest that self-other comparisons engage these self-relevant neural structures. Lindner et al. (2015) found that being exposed to a better performing standard induces increased BOLD response in the AI and the dorsal MPFC (DMPFC). Moore, Merchant, Kahn, and Pfeifer (2014) asked participants to compare their personal characteristics on a list of several adjectives and observed an interaction between the level of self-involvement and the similarity with the comparison standard in the bilateral AI and in the ventral ACC (vACC). Similarly, Beer and Hughes (2010) requested students to evaluate their own personality in relation to an average peer and reported activity in the MPFC, the ACC, and in the insula as a function of the similarity and valence of the comparison. These studies thus speak in favor of a recruitment of these neural structures by social comparison. However, these results are difficult to interpret with regard to the literature on magnitude comparisons since they rely on different kinds of paradigms. The present study aims at filling this gap.

The objective of the present study was to investigate whether self-other comparisons rely on the activity of these self-relevant structures instead of frontoparietal regions. To this end, we asked female participants to compare their own attractiveness – or the attractiveness of a familiar woman – to a series of photographs showing female faces (see Figure 1) and we exposed them to a distance effect paradigm. At a behavioral level, we tested the hypothesis that comparing one's own attractiveness to similar targets elicits longer RTs than comparisons with dissimilar targets. At the brain level, we intended to test whether low distance self-other comparisons engage self-related regions, i.e., the MPFC, the AI and the ACC, to a greater extent than high distance comparisons. Finally, one characteristic of self-other comparisons is that the direction of the comparison is crucial: Comparisons with upward standards are likely to elicit negative emotions (Beer & Hughes, 2010; Lindner et al., 2015), whereas downward comparisons may rather be rewarding (Bault, Joffily, Rustichini, & Coricelli, 2011; Fliessbach et al., 2007). Thus, in the present study, we modelled in the parametric design the *direction of the comparison* (upward vs downward) in addition to the *comparison targets* (self-other vs familiar-other) and the *perceived distance between the two comparison targets* (high vs low distance) to produce a 2 × 2 × 2 design.

Methods

Participants

We recruited twenty right-handed British Caucasian women with normal or corrected-to-normal vision (M = 20.06 years, SD = 1.43). Two participants had to be excluded from the final analyses, one because of technical issues and the other one because she felt unwell in the scanner. The fMRI study as well the behavioral pretests performed to produce thoroughly controlled material were approved by the ethics committee of Cardiff University School of Psychology. Prior to scanning, all participants gave their written informed

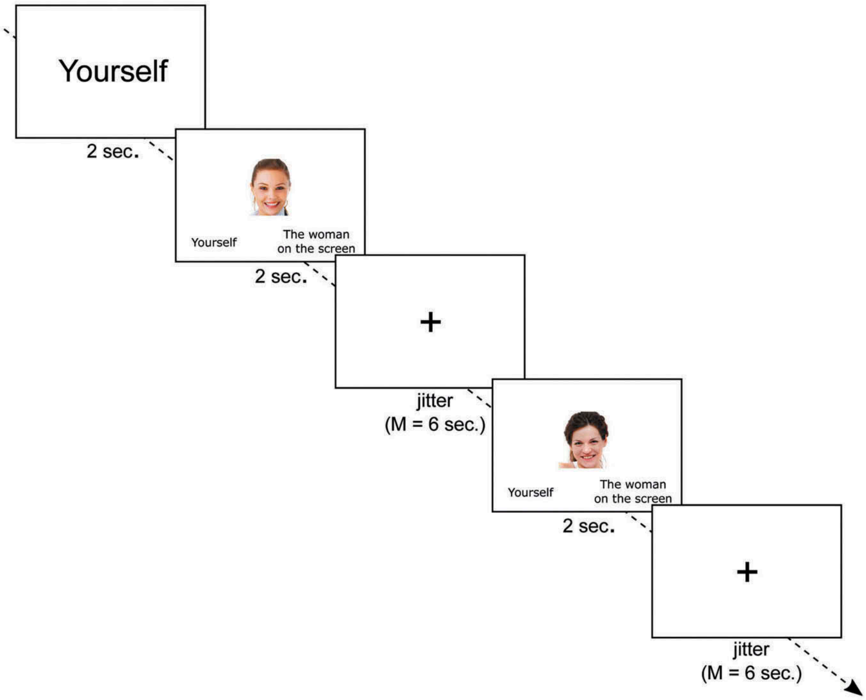

Figure 1. Experimental trials. Stimuli were colored pictures of female faces. Participants' task was to compare their own physical attractiveness (self-other) or the physical attractiveness of a familiar other woman (familiar-other) to the female targets presented on the screen. They were instructed to press the left button if they considered themselves (or their familiar other) as more attractive and the right button if they judged the woman on the screen as more attractive. A trial consisted of a female face presented for 2 s followed by an exponentially jittered fixation cross lasting on average 6 s. There were 240 trials in total: 120 in the self-other condition and 120 in the familiar-other condition. The experiment was divided into three runs of 80 trials each (40 self-other trials and 40 familiar-other trials). The order of the runs was counterbalanced across participants. Within one run, stimuli were organized in blocks of 5 trials preceded by a 2 s screen announcing the standard to compare ("Yourself" vs "Your familiar other"). A block of rest (40 s) consisting of a fixation cross was presented every four active blocks.

consent according to the Declaration of Helsinki. All participants from the fMRI and pretest studies received monetary compensation.

Stimuli

Stimuli were colored photographs of 240 female faces collected from a commercial online image data base (http://en.fotolia.com/). These pictures were selected from a set of 335 photographs of women, whose attractiveness had been assessed by a separate sample of British female participants ($N = 22$; $M_{age} = 20.77$ years, $SD_{age} = 3.46$). The pretest participants judged the attractiveness of the sequentially presented faces using an analogue scale composed of 100 points ranging from very unattractive to very attractive. Based on these ratings, we selected 240 pictures covering a spectrum from low to high attractiveness and associated with low standard deviations. We then divided these pictures into two sets of 120 faces of similar attractiveness (see Supplementary Material for detailed information about picture selection).

These pictures represented unknown Caucasian women seemingly in their twenties, so our participants could easily compare themselves (or their familiar other) to these women (for examples, see Figure 1). Their heads were straight or slightly tilted with their full face in view. They had a neutral or smiling facial expression and they were gazing directly at the camera (the ratio of neutral to smiling faces was the same in both conditions).

Procedure

Standard selection

In the days before the fMRI session, participants were asked to complete an online questionnaire created with the objective of selecting the comparison standard for the familiar-other condition. Participants had to list the names of 10 familiar women who were close to their own age (±5 years) and with whom they were in regular contact at the time of the study. As previous research has shown that people sometimes integrate close others into their self-concept (Aron, Aron, Tudor, & Nelson, 1991), we told our participants that their familiar others should not be intimate friends or close relatives but nevertheless women whom they could easily picture in their minds (colleagues, students attending the same classes, friends of friends etc.). Participants were then asked to assess the attractiveness of each familiar woman as well as 5 distractor dimensions (self-confident, dynamic, trustworthy, outgoing, friendly to stranger) on 7-point scales ranging from 1 (not at all) to 7 (very much). Participants also performed the same evaluations for themselves at the end of the questionnaire. We used these ratings to select a standard for the familiar-other comparisons whose attractiveness rating was the closest to the participant's own rating. 14 out of the 18 participants listed at least one standard with exactly the same rating as their own. For the 4 remaining participants, the standard with the closest attractiveness rating differed by only one point from their own rating. Across the whole sample there was no significant difference between participants' self attractiveness ratings and the ratings of their selected standard (M_{self} = 4.39, SD_{self} = 0.79; $M_{standard}$ = 4.50, $SD_{standard}$ = 0.86; t(17) = 1.00, p = .33).

Experimental task

During fMRI scanning, participants performed an attractiveness comparison task using a 2 (comparison targets: self-other vs familiar-other) × 2 (direction: upward vs downward) × 2 (distance: low vs high) experimental design. Stimuli were presented using the E-Prime 2.0 software (Psychology Software Tools, Pittsburgh, PA). Participants viewed stimuli via a 45° angled mirror positioned above the head coil reflecting the projection of a computer screen. A trial consisted of a female face presented on a white background for 2 s followed by an exponentially jittered black fixation cross lasting on average 6 s (SD = 4.82). Participants responded with a fMRI-compatible response pad by pressing the left button if they considered themselves (or their familiar other) as more attractive and the right button if they judged the woman on the screen as more attractive. They had the possibility to respond during the face presentation screen as well as during the following fixation cross. Trials that did not lead to any responses (namely 3.43% of the total number of trials) were discarded from all subsequent analyses.

There were 240 trials in total: 120 in the self-other condition and 120 in the familiar-other condition. The experiment was divided into three runs of 80 trials each (40 self-other trials and 40 familiar-other trials). The order of the runs was counterbalanced across participants. Within one run, stimuli were organized in 8 blocks of 5 trials preceded by a 2 s instructions announcing the standard to compare ("Yourself" vs "Your familiar other"). Thus, each block lasted 42 s. Blocks were presented in a counterbalanced order. A block of rest (40 s) consisting of a fixation cross was presented after four task blocks. Participants were instructed outside of the scanner and performed a 6 trial practice with different stimuli as those used for the fMRI task.

Following the fMRI session, participants were asked to rate the attractiveness of the 240 faces on the same 100-point analogue scale used for the pretest (ranging from *very unattractive* to *very attractive*). In accordance with the pretest results, the analysis of these post-hoc attractiveness ratings did not reveal any difference between the pictures displayed in the self-other, Mean ratings = 53.22, Mean SD = 14.47, and the familiar-other conditions, Mean ratings = 53.41, Mean SD = 14.25; t(238) = 0.10, p = .92 (see Supplementary Material for more detailed results).

fMRI acquisition, preprocessing, and analysis

We acquired the data on a 3T GT HDx system (General Electric, Milwaukee, USA). We acquired the functional (T2*-weighted) images using blood oxygenation level dependent (BOLD) contrast (repetition time TR = 2000 ms; echo time TE = 35 ms; FoV = 220 mm; flip angle = 90°; matrix = 64 × 64; 1 volume = 35 axial slices; slice thickness = 3.4 mm; no gap; voxel size = 3.4 × 3.4 × 3.4 mm^3). We discarded the first 6 scans of each run to allow for scanner equilibration. A total of 1308 volumes remained corresponding to three runs of 436 images.

We analyzed the data with Statistical Parametric Mapping (SPM8 software, Wellcome Department of Imaging Neuroscience, London, UK; www.fil.ion.ucl.ac.uk/spm; Friston et al., 1994) implemented in Matlab R2013b. To compensate for timing differences during functional volume acquisitions, the images were submitted to a slice timing correction using the middle slice as reference slice. The images were realigned to the first volume and unwarped to correct for head movement. Then, we normalized the images into the Montreal Neurological Institute (MNI) standard space using the mean of the functional volumes. During normalization, we resampled the images at a voxel size of 3 × 3 × 3 mm^3 and afterwards spatially smoothed them with a FWHM 9 × 9 × 9 Gaussian kernel. We analyzed individual subject data based on the general linear model (GLM), providing contrasts for group effects analyzed at the second level.

At the first level, we modeled each of the eight experimental conditions (self-other vs familiar-other, upward vs downward, high vs low distance comparison conditions) with a reference vector of the stimulus onsets convolved with the canonical hemodynamic response function implemented in SPM8. We filtered low-frequency signal drifts using a cutoff period of 120 s. To remove variations in signal due to movement artifacts, we included the movement parameters calculated during the realignment in the model as parameters of no interest. We created contrasts of the experimental conditions that were then entered into a second-level group analysis using a full-factorial ANOVA employing a random-effects model.

Whole brain analyses

At the second level, we investigated with whole-brain analyses the main effects and interactions of the factors *comparison targets* (self-other vs familiar-other), *direction* (upward vs downward), and *distance* (low vs high distance).

Regarding the factor *direction*, we categorized trials as *upward* or *downward* trials based on participants' answers during fMRI scanning: Trials for which the participants had judged that they (or their familiar other) were more attractive than the target on the screen were considered as downward trials and those for which they had judged themselves (or their familiar other) as less attractive were considered as upward trials.

To investigate the effect of distance we split the trials into low and high distance conditions based on the post-hoc attractiveness ratings. As mentioned earlier, after the fMRI session participants had to rate the attractiveness of all the targets seen in the scanner, as well as their own attractiveness and the attractiveness of their familiar other. Thus, we created difference scores between participants' own ratings (or their familiar others' rating) and each target rating. Then in each condition (i.e., self-other-upward, self-other-downward, familiar-other-upward, familiar-other-downward), we performed median-splits to categorize the trials with the smallest difference scores in absolute value as low in distance and those with the greatest difference scores as high in distance.

The whole-brain analyses suggested a trend towards a statistical interaction between *distance* and *targets*. In order to specify this interaction, we investigated the distance effects in the self-other and familiar-other conditions separately.

Moreover, in order to test whether the differences in brain activity revealed by the distance effects were caused by differences in task difficulty, we ran the same analyses as described above but, in addition, we modeled the response times at the first level (for each trial of each participant) as parameters of no interest.

For the whole-brain analyses, we report neural changes below a voxelwise statistical threshold of $p < .001$ uncorrected for multiple comparisons and a cluster extent threshold of $p < .05$ FWE corrected for multiple comparisons. In addition, for regions and contrasts for which we had hypotheses, we report trends using a more lenient threshold (voxelwise statistical threshold of $p < .001$ uncorrected for multiple comparisons and a cluster extent of 5 voxels). Statistical maps were labeled using the MRIcro atlas (http://www.mricro.com) and the Talairach and Tournoux atlas (Talairach & Tournoux, 1988).

Region of interest analyses

To confirm possible differential effects in brain regions previously associated with self-information processing and self-other comparisons, we used a region of interest (ROI) approach investigating the MPFC, ACC and AI. Research suggests that the ventral and dorsal parts of the medial frontal cortex are differentially associated with judgments of similar and dissimilar others (Jenkins, Macrae, & Mitchell, 2008; Mitchell, Banaji, & Macrae, 2005; Mitchell, Macrae, & Banaji, 2006). Therefore, in our ROI approach, we made a distinction between the ventral and dorsal MPFC and ACC. Thus, we extracted for each experimental condition the mean activation values in the bilateral AI, vACC, dACC, VMPFC, DMPFC and in the ventral striatum. For that we used the AAL atlas masks provided by the SPM toolbox Marsbar (http://marsbar.sourceforge.net/; Tzourio-Mazoyer et al., 2002). For the AI, we created a ROI encompassing the anterior part of the Marsbar ROI over the insula. For the ACC, we divided the Marsbar ROI over the ACC in a ventral and dorsal parts. For the ventral striatum, we created a ROI of the ventral part of the caudate nucleus encompassing most of the coordinates reported in previous studies describing reward activation in response to downward comparisons (see Supplementary Material and Supplementary Tables 1 and 2 for detailed information about the creation of the ROIs including). We then analyzed these results using repeated measure ANOVAs in SPSS.

Results

Behavioral data

Reaction times

We calculated mean reaction times (RTs) for every subject in each condition (see Figure 2). These means were submitted to a 2 (targets) × 2 (direction) × 2 (distance) repeated measure ANOVA.

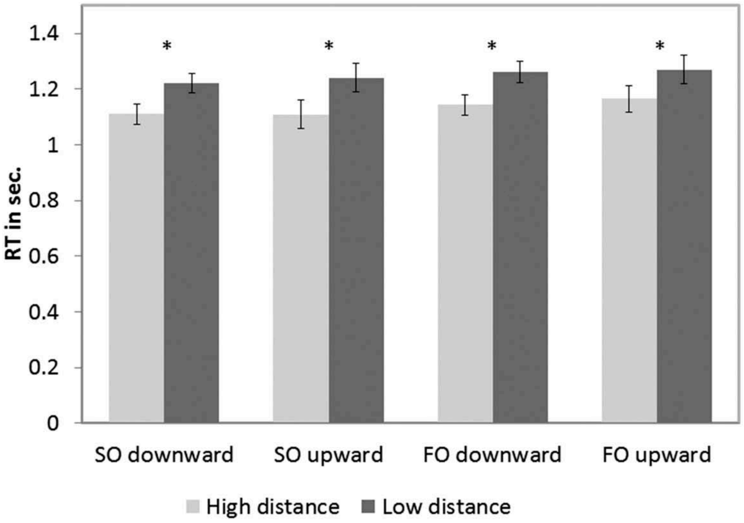

Figure 2. Response times in the different experimental conditions. Error bars represent ±s.e.m. * $p < .001$. SO: self-other; FO: familiar-other.

The main effect of *targets* was significant: Participants responded faster to self-other than familiar-other comparisons, $F(1,17) = 9.541$, $p = .007$; $\eta^2 = .36$). We did not find any effect of *direction*, $F(1,17) = 0.29$, $p = 0.60$; $\eta^2 = .02$, but the distance effect was significant, participants being faster for high distance than low distance comparisons, $F(1,17) = 67.15$, $p < .001$; $\eta^2 = .80$. Post-hoc two-tailed *t*-tests applied with a Bonferroni correction testing the effect of distance for each direction and target category indicated that participants were faster for high distance than low distance trials, for self-other-downward: $t(18) = 4.51$, $p < .001$, $d = 1.37$; for self-other-upward: $t(18) = 4.12$, $p = .001$, $d = 1.50$; for familiar-other-downward: $t(18) = 3.60$, $p = .002$, $d = 1.34$; for familiar-other-upward: $t(18) = 4.03$, $p = .001$, $d = 1.20$. We did not observe any significant two-way or three-way interaction, all $Fs < 0.62$, all $ps > .44$.

Comparison decisions

We also analyzed the responses made by the participants in the scanner when comparing their attractiveness in order to see if they displayed any self-serving bias. First, we tested if the frequency of upward and downward responses varied as a function of the standard they were instructed to compare (self vs familiar other). We submitted these frequencies to a 2 (standard) × 2 (direction) × 2 (distance) repeated measure ANOVA but did not observe any significant main effect or interactions, all $Fs(1,17) = 4.21$, $ps > .056$; $\eta^2 < .20$ (see Supplementary Table 3 for mean values and the Supplementary Material for information regarding the correspondence between responses in the scanner and post-hoc ratings).

fMRI data: whole brain analyses (see Table 1)

Main effect of distance

Low distance comparisons were associated with greater activity than high distance comparisons in the bilateral AI and in a cluster encompassing the DMPFC, the dACC and the supplementary motor area (SMA, see Figure 3). Even at a more lenient threshold, we did not observe any significant cluster in parietal or dorsolateral prefrontal regions. The opposite contrast (High distance > Low distance) did not lead to any significant activations.

Main effect of targets

We found that self-other comparisons triggered more activity in a cluster comprising the MPFC and the vACC, in the right fusiform gyrus and in the left inferior occipital gyrus (IOG) than familiar-other comparisons. The opposite contrast (familiar-other > self-other) did not lead to any significant activations at any threshold.

Main effect of direction

At a corrected threshold, we did not observe any main effect of direction. At a more lenient threshold of $p < .001$ uncorrected for multiple comparisons and a cluster extent of 5 voxels, our results indicated greater activation in the left AI for upward than downward comparisons. The opposite contrast (Downward > Upward) did not lead to any significant activations at either threshold.

Interactions

At a corrected threshold, we did not observe any significant interaction. However, at a threshold of $p < .001$ uncorrected for multiple comparisons and a cluster extent of 5 voxels, in

Table 1. Coordinates of activation.

Regions	Side	Cluster Size (voxels)	MNI coordinates x	y	z	z-Scores
Low > High distance						
Anterior insula	L	343	−33	26	7	5.49
	R	442	33	20	−14	5.43
SMA/DMPFC	L/R	790	6	17	46	5.40
Extending to the dACC			−9	23	28	4.82
Self-Other > Familiar-Other						
vACC/MPFC	L/R	476	3	47	7	4.56
Fusiform gyrus	R	194	27	−76	−5	5.01
Inferior occipital gyrus	L	451	−30	−88	−5	4.33
Upward > Downward						
Anterior insula*	L	14	−30	17	13	3.69
Interaction Distance-Target (i.e., stronger distance effect for self-other than other-other comparisons)						
vACC*	L/R	32	9	32	4	3.53
dACC*	L/R	22	−6	29	22	3.59
Anterior insula*	L	9	−30	14	−14	3.34
Low > High distance for self-other comparisons						
Anterior insula	L	426	−33	26	7	5.49
	R	509	33	20	−14	5.18
SMA/DMPFC	L/R	861	−6	26	22	5.03

The clusters displayed in this table were selected with a threshold of $p < .001$ uncorrected for multiple comparisons and a cluster extent threshold of $p < .05$ FWE corrected for multiple comparisons, with the exception of those marked with an asterisk (*). These later values correspond to regions where we had hypotheses but did not survive correction and are here reported with a threshold of $p < .001$ uncorrected for multiple comparisons and a cluster extent threshold of 5 voxels. dACC, dorsal anterior cingulate cortex; vACC, ventral anterior cingulate cortex; DMPFC, dorsal medial prefrontal cortex; SMA, supplementary motor area.

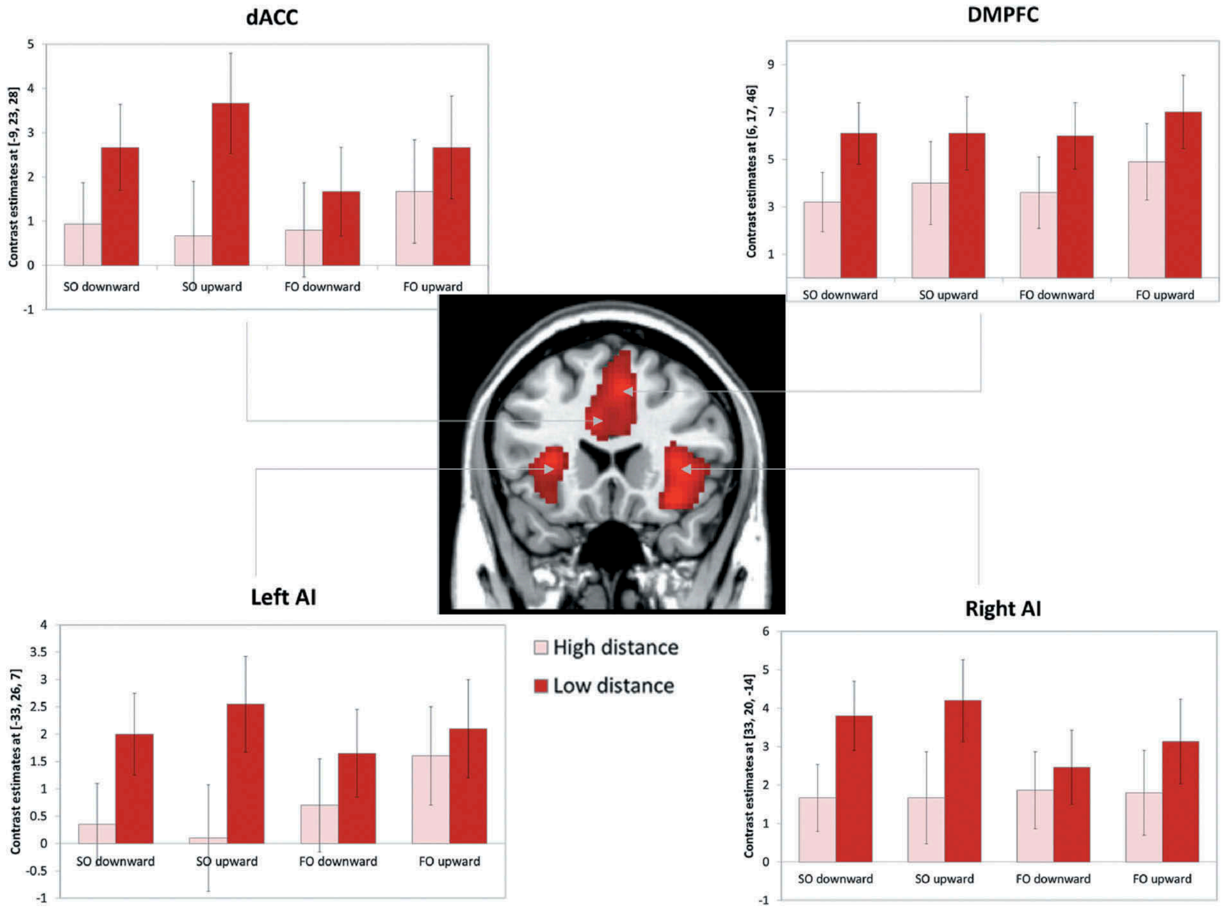

Figure 3. Main effect of *distance*. The center of the figure represents the statistical parametric map overlaid onto the canonical MNI brain issued from the whole-brain random-effect analysis (voxel level $p < .001$, cluster extent threshold of $p < .05$ FWE corrected for multiple comparisons). The histograms display the parameter estimates at peak voxels in the left (MNI coordinates: x, y, z = −33, 26, 7) and right anterior insula (AI, MNI coordinates: x, y, z = 33, 20, −14) and in a cluster encompassing the dorsal anterior cingulate cortex (dACC, MNI coordinates: x, y, z = −9, 23, 28) and the dorsomedial prefrontal cortex (DMPFC, MNI coordinates: x, y, z = 6, 17, 46). SO: self-other; FO: familiar-other.

accordance with our main hypothesis of different neural correlates for self-other and familiar-other distance effects, we found a significant interaction between the factors *distance* and *comparison targets*. This interaction seems to result from a stronger distance effect in the AI, the vACC and the dACC for self-other comparisons than familiar-other comparisons. Indeed, the analysis of the distance effect in the self-other and familiar-other conditions separately suggested that the main effect of distance we observed was mainly driven by self-other comparisons. In the self-other conditions, low distance comparisons elicited stronger activation in the bilateral AI and in the DMPFC/dACC, whereas the distance effect in the familiar-other conditions did not lead to any significant activation. All other two-way and three-way interactions were non-significant at both corrected and non-corrected thresholds.

Main effects and interactions with RTs as covariates

We replicated all these results when controlling for response times (see Supplementary Table 4). The analyses with the RTs as covariates led to similar clusters of activated voxels suggesting that task difficulty, as measured by response times, does not account for the results we observe. On the contrary, we then even found that the interaction between the factors *distance* and *targets* in the ACC became significant at a corrected extent threshold.

fMRI data: ROI analyses

In order to control for Type I error when testing the hypothesis that self-other comparisons specifically exhibit a distance effect in self-relevant regions, we performed ROI analyses of the vACC, dACC, AI, VMPFC, and DMPFC. Previous studies have reported joint activity in these regions for tasks requiring self-judgment (Araujo et al., 2013) and social comparison (Beer & Hughes, 2010; Kedia, Lindner, Mussweiler, Ihssen, & Linden, 2013; Lindner et al., 2015; Moore et al., 2014). Moreover, research shows that these brain areas are structurally (Ghaziri et al., 2017) and functionally connected to each other (Cauda et al., 2012, 2011; Dosenbach et al., 2006; Penner et al., 2016; Sridharan, Levitin, & Menon, 2008; Taylor, Seminowicz, & Davis, 2009). Therefore, we combined the values obtained for each of these ROIs in a 5 (region: AI, vACC, dACC, VMPFC, & DMPFC) × 2 (hemisphere: left vs right) × 2 (targets: self-other vs familiar-other) × 2 (direction: upward vs downward) × 2 (distance: high vs low) repeated measure ANOVA. For the sake of concision, we only report here significant main effects and interactions concerning our three main factors of interest (*targets, direction* and *distance*). However, all results can be found in the Supplementary Material (see Supplementary Table 5).

In accordance with our assumption that these 5 regions are self-relevant, we found a main effect of *targets* corresponding to higher values for self-other than familiar-other comparisons, $F(1,17) = 10.88$, $p = .004$; $\eta^2 = .39$. Moreover, we observed a significant two-way interaction between the factors *targets* and *distance* suggesting, as we had hypothesized, a larger distance effect in these regions for self-other comparisons than familiar-other comparisons, $F(1,17) = 6.08$, $p = .025$; $\eta^2 = .26$.

Some of these effects were stronger in some regions than others: We found two-way interactions between the factors *region* and *distance*, $F(1,17) = 8.84$, $p < .001$; $\eta^2 = .34$, and between the factors *region* and *targets*, $F(1,17) = 6.63$, $p < .001$; $\eta^2 = .28$. Thus, we performed post-hoc 2 (hemisphere) × 2 (targets) × 2 (direction) × 2 (distance) ANOVAs in each region separately to identify those exhibiting the expected pattern. To avoid reporting false positive results due to multiple testing, we set the significance threshold of these post-hoc tests to the Bonferroni corrected value of $p < .01$. These ANOVAs revealed a significant main effect of *distance*, i.e., stronger activations for low than high distance, in the AI and the dACC, as well as a main effect of *targets* in the vACC, dACC and DMPFC, indicating that these regions responded with higher activation to self-other than familiar-other comparisons, all $Fs > 9.65$, $p < .006$; $\eta^2 > .25$ (see Supplementary Tables 6–10 for more detailed results regarding the region by region ANOVAs and Supplementary Table 12 for the mean values of activation in each ROI and experimental condition).

We also investigated the ventral striatum with ROIs. To test the hypothesis that downward comparisons involving the self activate reward related brain regions (Fliessbach, Elger, Falk, & Weber, 2012), we ran a 2 (left vs right hemisphere) × 2 (self-other vs familiar-other) × 2 (upward vs downward) × 2 (high vs low distance) ANOVA on the values extracted in the ventral striatum. Results indicated that, contrary to what we were expecting, the interaction between the factors *targets* and *direction* was not significant, $F(1,17) = 0.259$, $p = 618$; $\eta^2 = .015$ (see Supplementary Tables 11 and 12 for more detailed results).

Discussion

The present study aimed at investigating the neural correlates of self-other and familiar-other comparisons with an original paradigm inspired by research on magnitude comparisons (Cohen Kadosh et al., 2005).

Previous research has found that comparing the attractiveness of two unknown women elicits a behavioral distance effect accompanied by the activity of a fronto-parietal network known for its role in nonsocial magnitude processing (Kedia et al., 2014). In the present study, we tested the hypothesis that comparisons involving the self undergo different brain processing.

In line with this previous research, we found that participants were slower to compare targets close in attractiveness irrespectively of whether the comparison involved the self or a familiar other. Interestingly, however, this behavioral distance effect did not elicit any activity in the comparative network identified by research on magnitudes and person comparisons. Instead of the bilateral IPS, the DLPFC and the cerebellum, in the present study we found that shorter distance comparisons triggered activity in the bilateral AI, in the MPFC and the ACC. Not only did we observe a distance effect in these regions but we also found that this effect was stronger for self-other than familiar-other comparisons.

The AI, the pregenual ACC, and the MPFC, the regions that we observe in the interaction between distance and target in the ROI analysis, have been associated with self-evaluations in several previous studies. Meta-analyses of functional neuroimaging studies point to a central role of these regions in self-related judgments as compared to other-related ones (Araujo et al., 2013; Denny, Kober, Wager, & Ochsner, 2012). Self-specific activations in the pregenual ACC and vMPFC have been shown to overlap with the default mode network (DMN), a set of brain regions commonly activated at rest and that may serve self-reference functions (Qin & Northoff, 2011). DMN regions are down-regulated during most active tasks, which may explain why in our studies the vACC and the vMPFC display deactivations rather than activations (see Supplementary Table 12).

The AI and the ACC are also critical neural substrates for emotional awareness. The AI has been associated with somatotopic representations of bodily states such as itch, pain, temperature perception as well as physical and moral disgust (Gu et al., 2013; Harris & Fiske, 2006; Wicker et al., 2003). Similarly, activity in the ACC has been shown to correlate with pain intensity and seems to be elicited by painful social situations such as ostracism (Eisenberger, Lieberman, & Williams, 2003; Emmert et al., 2014). At a more generic level, the AI and the ACC have been assumed to enable the detection of and reaction to the most salient events thanks to their particular connections. The AI receives multimodal inputs from sensory cortices and relays this information to the ACC via the von Economo Neurons (VENs), a category of neurons equipped with large axons to enable rapid conduction. The ACC would then facilitate response selection via its link to motor areas (Gasquoine, 2014). Menon and Uddin (2010) propose that the role of the AI is to identify relevant stimuli from the vast and continuous stream of information perceived by the senses. Once such stimuli are detected, the AI facilitates information processing by engaging brain areas mediating attention, working memory and higher order cognitive processes, such as the ACC and the DLPFC.

The present experiment does not allow us to make definite inferences regarding the functions sustained by the brain regions activated by our experimental conditions. However, it may be interesting to note that the conditions that seem to elicit the stronger activations in the AI, the ACC and the DMPFC, i.e., low distance self-other comparisons and upward comparisons, are also those identified as mostly relevant by Social Comparison Theory. Indeed, social psychologists have demonstrated that people are inclined to compare themselves to *similar others*. As Festinger (1954), the father of Social Comparison Theory, argued in his fundamental article, comparisons with people whose characteristics strongly diverge from one's own are not very informative because the result of such a comparison is known beforehand (for review see Corcoran, Crusius, & Mussweiler, 2011). Thus, when they need to evaluate themselves, people naturally seek out for similar others and usually select them for being slightly better (Wheeler, 1966). It may be, therefore, worth noting that the standards one could assume to be the most relevant based on social psychological literature are those eliciting, in the present study, the highest levels of activation in the AI, the ACC and the MPFC.

An alternative interpretation of our results relates to the role of these regions in decision-making. In the present study, we used the distance between the two targets as a manipulation of the intensity of the comparative process. However, low distance comparisons do not only require a more demanding comparative process. As they are more difficult than high distance comparisons, they also engage a whole range of other non-specific cognitive processes, such as conflict, uncertainty and error processing, that are known to also recruit the AI, the dACC and the DMPFC (Neta, Nelson, & Petersen, 2016; Neta, Schlaggar, & Petersen, 2014). Therefore, to rule out the hypothesis that the activations we observed are simply due to the higher task difficulty of low distance comparisons, we reanalyzed the data after having regressed out the RTs. We found that controlling for the RTs did not alter the results: Both the main effect of distance and the distance-target interaction remained significant, suggesting that these effects cannot solely be explained by task demands.

Our results are in line with previous neuroimaging research on social comparison, such as Moore et al. (2014) who also found that self-other comparisons with a similar peer elicit stronger activations in a cluster located in the VMPFC/ACC than other kinds of social comparisons (i.e., comparison with dissimilar peers or comparisons involving two external persons). Moreover, similar results were found by Lindner et al. (2015), who asked medical students to perform a knowledge quiz in the fMRI scanner. After each question, participants received a feedback displaying the accuracy of their own response as well as the success rate of a reference group composed of other medical students. Consistent with our results, they found enhanced activity in the AI and the DMPFC when the comparisons were unfavorable for the participant. Taken together our results converge with other studies to attribute a central role to the AI, the ACC and the MPFC in self-other comparisons with close standards.

In the present study we did not observe, however, activations in the ventral striatum (VS) for downward comparisons, although such activations have been reported on several occasions before (Bault et al., 2011; Dohmen, Falk, Fliessbach, Sunde, & Weber, 2011; Du et al., 2013; Dvash, Gilam, Ben-Ze'ev, Hendler, & Shamay-Tsoory, 2010; Fliessbach et al., 2007, 2012; Grygolec, Coricelli, & Rustichini, 2012; Kang, Lee, Choi, & Kim, 2013; Lindner et al., 2015; for a review see Kedia et al., 2014). The VS constitutes one of the main structures of the reward system. Several studies using reinforcement learning paradigms based on monetary rewards have demonstrated that striatal activity is contingent on the relative value of a reward: The VS reacts not only to the absolute amount of money earned but also to how much was earned in comparison to other people. The fact that, in the present study, favorable attractiveness comparisons were not found to trigger activity in the VS is difficult to interpret. Absence of significant results is not evidence of absence. Other studies investigating self-other comparisons of fixed personal characteristics, such as hierarchical status, intelligence, or height, also failed to find VS activity for self-flattering contrasts (Kedia et al., 2013; Zink et al., 2008; see also Beer & Hughes, 2010). This null result could be due to a lack of power or a poor signal to noise ratio as the striatum is known to suffer from signal dropout. Another possibility is that money-based and trait-based social comparisons elicit different responses in the brain reward system. Future research should address this question. Moreover, future experiments should also test whether the effects reported in the present article replicate in a male sample, as our study only investigated women.

Conclusion

The results of the present study point to specific neural processes underlying self-other comparisons. At the behavioral level attractiveness comparisons involving the self may resemble comparisons of simple magnitudes and numbers; however, at the brain level, instead of frontoparietal activations related to magnitude processing, they engage self-relevant brain structures, such as the frontal and insular cortex.

Acknowledgment

The authors would like to thank Katja Corcoran for her scientific advices and kind support.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the bilateral program between the Economic and Social Research Council of the UK (ESRC); and the German Research Foundation (DFG) under Grant number: RES-062-23-0946: The Neural Substrates of Social Comparison.

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