The neural substrates of person comparison—An fMRI study

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Introduction

In order to master the complexity of social interaction, people have to understand and predict the behavior of others. This requires trait judgments that are critically shaped by person comparisons (Dunning and Hayes, 1996; Higgins and Lurie, 1983). People’s fundamental propensity to process social information comparatively has always played a prominent role in social psychology (Festinger, 1954; Higgins and Stangor, 1988). Particularly judgments about personal qualities often involve comparisons (Dunning and Hayes, 1996; Festinger, 1954; Mussweiler, 2003). Regardless of its remarkable psychological importance, little is known about the neural substrates of person comparison. This study was designed to fill this gap and delineate how, on a neural level, person comparisons differ from non-comparative person judgments.

Comparative social judgments may be supported by a generic network for comparative judgments as described for various categories of inanimate objects, involving mainly regions along the intraparietal sulcus (IPS) (Cohen-Kadosh et al., 2005; Pinel et al., 2004). Alternatively, the neural representation of comparative judgments may be organized along basic content domains into a social and non-social realm. We hypothesise that comparisons in the social realm are indeed a special case. When comparing people, particularly on psychological characteristics like intelligence, beliefs, intentions, and attitudes of the two persons and take their perspective into account. That is, they try to understand other people’s behavior in terms of their mental states — which is a specific human ability termed mentalizing or Theory of Mind (ToM) reasoning (Premack and Woodruff, 1978). Functional imaging research has helped identify a distributed neural system underlying ToM, including the right and left temporo-parietal junction (TPJ), the precuneus, right and left posterior superior temporal sulcus (pSTS) and the medial frontal cortex (MFC) (Brunet et al., 2000;...
In the present functional magnetic resonance imaging (fMRI) study, we contrasted comparative and non-comparative judgments about the same persons, and comparative judgments on psychological and physical dimensions. Participants were presented with names of two celebrities. In the non-comparative judgment, participants had to decide whether one of the two celebrities was a musician (or politician). The two comparative judgments were which of the two celebrities was more intelligent and which celebrity was taller. We hypothesized that in comparative person judgment, along with the activation of regions representing semantic person knowledge (Mason et al., 2004; Mitchell et al., 2002) comparison specific activity should be found. In addition, we expected ToM areas to be more activated during intelligence comparisons because comparison of psychological characteristics (intelligence) involves taking the person’s own perspective into account. Our design thus entailed a comparison task with different degrees of perspective taking and a purely semantic non-comparative task as control condition. We did not try and include a control condition with a social but non-comparative task (e.g., how intelligent is X?), because comparisons are spontaneously engaged even if a person characteristic is judged without explicitly asking for comparison (Dunning and Hayes, 1996; Mussweiler et al., 2004).

Materials and methods

Participants

Previous research has demonstrated that the perceived height of another person depends on the participants' own height, leading to clear gender differences (Biernat et al., 1991). As a consequence, it is impossible to design stimulus material that is perceived similarly by male and female participants. Hence, fourteen healthy male, right-handed participants were recruited from an academic environment (mean age 27.93, SD 4.67). The Ethics Committee of the Medical School of the Johann Wolfgang Goethe University approved the study. Written informed consent was obtained from all participants prior to scanning.

Stimuli

A set of 64 pairs of surnames of 47 celebrities served as stimulus material. The individual names had been tested for 100% familiarity on N=20 male students. Pairs of names were presented in white font (font: Arial, height: 4.6°) on a black background above and below the centre of the screen. The distance between centre of word and centre of screen was 4.4°. The four cue stimuli had the same colour and font size. Stimulus presentation and recording of response time was controlled by the Presentation 9.9 software.

Fig. 1. Paradigm design. Four different tasks containing two experimental conditions (body height and intelligence comparison) and control condition (musician/politician). Each trial began with the presentation of a cue (1000 ms), followed by a fixation point (1000 ms) and a pair of stimuli (1000 ms). After 10 s (ITI) a new trial began. In the experimental conditions subjects had to decide which person, indicated by the names, was taller or more intelligent. In the control condition they had to decide whether a politician was present or whether a musician was present.
(Neurobehavioral Systems, Inc.). During scanning, the computer display was projected onto a mirror mounted on the head coil.

**Procedure**

The two experimental conditions required comparative judgments on intelligence or body height. Participants had to decide which of the two persons whose name appeared on the screen was more intelligent or taller. In the control condition participants had to indicate whether the stimulus pair included the name of a musician/politician. We did not expect to detect differences between the two categorizations required in the control condition (musician and politician). Hence, we used a design with an experimental condition with two levels and a control condition with only one level. In all three conditions, participants were asked to respond as quickly as possible by using a two-button fiber-optic response box.

Participants performed the experiment while undergoing fMRI. The experiment was divided into two runs of approximately 17 min. Each run started with a 20 s instruction on key-assignment, followed by contained 64 trials (16 per condition) in a pseudo-randomized order. Each trial began with one of four cues (see Fig. 1) indicating the task instruction, presented for 1000 ms at the centre of the screen. After the cue disappeared an “x” as a fixation point appeared for 1000 ms, followed by a pair of stimuli appearing for 1000 ms. The inter trial interval (ITI) was 10 s (see Fig. 1). The experiment was preceded by a training session with eight trials which we served to familiarize participants with the timing of the task and the response box.

**Imaging procedure**

We collected whole-brain MRI data on a 3T TRIO Magnetom (Siemens, Erlangen, Germany). We acquired echo-planar imaging data for fMRI using standard parameters (Field of view, 200 mm; matrix: 64×64; 1 volume=16 axial slices, 5 mm slice thickness; in-plane resolution, 3.128 mm; repetition time (TR): 1000 ms, echo time (TE): 30 ms; flip angle: 60°; 1006 volumes per run). We synchronized stimulus presentation with the fMRI sequence at the

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Fig. 2. Group analysis with GLM of whole brain. Superposition maps of the contrast between comparison and control condition; x, y, z denote Talairach coordinates of slice planes. Higher activation for comparison is shown in orange and for control condition in blue. Effects were only shown if the associated p-value yielded p<0.01 (corrected for multiple comparisons). Top: Seven discrete local maxima in the large bilateral cluster in MFC (left and right APCC, two areas in the left prMFC, arMFC and two areas in the oMFC). Centre and bottom: bilateral OFC, left amygdala, left pH, bilateral PCC, left TPJ, bilateral IPL and two areas in right prMFC.
beginning of each trial. We acquired four dummy volumes before each run in order to reduce possible effects of T1-saturation. To minimize head motion, we used fixed head pads. We obtained a T1 weighted 3D anatomical scan (1 × 1 × 1 mm³ resolution) for each participant.

We pre-processed and analyzed the fMRI using BrainVoyager™ (Brain Innovation, Maastricht, The Netherlands). We applied the following pre-processing steps: slice-time correction, motion correction, linear trend removal, highpass temporal filtering with 3 cycles in time course and spatial smoothing using a Gaussian kernel of 8 mm full-width at half-maximum. We manually coregistered the fMRI data with the anatomical scans. We transformed the 3D anatomical scans into Talairach space (Talairach and Tournoux, 1988) and subsequently used the parameters for this transformation to transform the coregistered functional data. We then resampled the 3D functional data to set a voxel size of 3 × 3 × 3 mm³.

We defined each of the four conditions of the experimental design as a predictor. For defining the predictor we assumed a trial duration of one second following stimulus onset. We defined all cues and the following fixation points as a fifth predictor (2 s per event) and the instruction as a sixth (10 s). The remaining fixation volumes served as baseline. We convolved the predictors with a hemodynamic response function (Boynton et al., 1996). We used the FDR for correction of multiple comparisons. We implemented comparisons of interest as linear contrasts and required ROIs to exceed 50 contiguous voxels for contrasts between tasks. To find discrete local activation maxima in a large cluster we identified voxels with minimal p-values in subclusters of voxels with $p < 0.0001$. Around that putative activation maximum we defined a box with edge lengths of 10 voxels.

### Results

#### Behavioral data

Reaction times were highest for intelligence comparison 2125 ms (SD = 656), followed by body height comparison 1921 ms (SD = 507) and the control condition 1543 ms (SD = 433). Reaction times revealed significant condition effects for comparison vs. control conditions ($t(13) = 13.13, p < 0.0001$), intelligence vs. body height comparison ($t(13) = 12.101; p < 0.0001$) and intelligence comparison vs. control condition ($t(13) = 12.101; p < 0.0001$).

#### fMRI data

We used random-effects general linear model (GLM) for whole-brain and region of interest (ROI) analyses.

#### Whole-brain GLM

##### Contrast comparison versus control condition

The t-map for the contrast between comparison and control condition was thresholded at a False Discovery Rate (FDR) < 0.05. For

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Table 1

<table>
<thead>
<tr>
<th>Region</th>
<th>L/R</th>
<th>Talairach coordinates</th>
<th>BA Cluster size (in voxel)</th>
<th>p-values of GLM contrasts (Whole brain)</th>
<th>ROI Comparison vs. control</th>
<th>ROI Intelligence vs. control</th>
<th>ROI Body height vs. control</th>
<th>ROI Intelligence vs. body height</th>
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</thead>
<tbody>
<tr>
<td><strong>medial frontal cortex large</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>–prMFC</td>
<td>L</td>
<td>–11 29 50 8</td>
<td>8</td>
<td>$p &lt; 0.0001$</td>
<td>$p &lt; 0.0001$</td>
<td>$p &lt; 0.0001$</td>
<td>$p &lt; 0.0001$</td>
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<tr>
<td>–arMFC</td>
<td>L</td>
<td>–12 48 42 9</td>
<td>9</td>
<td>$p &lt; 0.0001$</td>
<td>$p &lt; 0.0001$</td>
<td>$p &lt; 0.0001$</td>
<td>$p &lt; 0.0001$</td>
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<tr>
<td>–oMFC</td>
<td>M</td>
<td>0 38 –8 11</td>
<td>11</td>
<td>$p &lt; 0.0001$</td>
<td>$p &lt; 0.0001$</td>
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<td>$p &lt; 0.0001$</td>
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<tr>
<td>–APCC</td>
<td>R</td>
<td>2 56 –3 11</td>
<td>11</td>
<td>$p &lt; 0.0001$</td>
<td>$p &lt; 0.0001$</td>
<td>$p &lt; 0.0001$</td>
<td>$p &lt; 0.0001$</td>
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<tr>
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<td>10</td>
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<td>$p &lt; 0.0001$</td>
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<tr>
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</tr>
<tr>
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<td>2377</td>
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<td>$p &lt; 0.0001$</td>
<td>–</td>
<td>$p &lt; 0.0001$</td>
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<tr>
<td>PCC</td>
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<tr>
<td>R</td>
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<td>127</td>
<td>$p &lt; 0.001$</td>
<td>–</td>
<td>$p &lt; 0.0001$</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>TPJ</td>
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<td>353</td>
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<td>$p &lt; 0.0001$</td>
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<td>–</td>
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<tr>
<td>pH</td>
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</tr>
<tr>
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<td>93</td>
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<td>$p &lt; 0.0001$</td>
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<tr>
<td>globus palladus</td>
<td>R</td>
<td>11 –3 –5</td>
<td>140</td>
<td>$p &lt; 0.001$</td>
<td>$p &lt; 0.0001$</td>
<td>$p &lt; 0.0001$</td>
<td>$p &lt; 0.0001$</td>
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Control > comparison

| IPL                  | L   | –56 –33 31 7          | 2199                       | $p < 0.0001$                           | $p < 0.0001$              | $p < 0.0001$              | –                          | –                                |
| L                    | 58 –14 30 7             | 208                       | $p < 0.0001$                           | –                        | –                          | –                          | –                                |
| R                    | 55 –36 34 7             | 441                       | $p < 0.0001$                           | $p < 0.0001$              | $p < 0.0001$              | –                          | $p < 0.0001$                      |
Fig. 3. BOLD time courses for all conditions (red = intelligence comparison, blue = body height comparison, dark and light green = control conditions). Top: areas showing significant differences in comparison versus control (left pH, left PCC and left OFC); center and bottom left and right: areas showing significant differences in intelligence comparison versus control and in intelligence versus body height comparison (center: left APCC, right prMFC and left TPJ; bottom: left prMFC and left oMFC); bottom right: left IPL showed significantly higher activation for control condition in contrasts intelligence comparison versus control condition and body height versus control condition.
this contrast both comparative judgments were combined to investigate areas which are involved in comparison tasks in general. Results are shown in Fig. 2 and Table 1. As can be seen in Fig. 2, several areas emerged in this contrast with significantly higher activation for the comparison condition, including the posterior portion of the right rostral medial frontal cortex (prMFC), left temporoparietal junction (TPJ) and left and right posterior cingulate cortex (PCC). Furthermore this contrast showed higher activation for comparison in left and right orbitofrontal cortex (OFC), left posterior hippocampus (pH), left amygdala and right globus pallidus (GP). Comparison conditions additionally revealed higher activation of a large bilateral cluster in medial prefrontal cortex including seven discrete local maxima. These maxima were left and right anterior paracingulate cortex (APCC), two areas in the left prMFC, an area in the anterior portion of the rostral medial frontal cortex (arMFC) and two areas in the orbital medial frontal cortex (oMFC). When we removed the cluster size threshold we also obtained small clusters in right TPJ and left GP, which also survived the threshold for a significant intelligence vs. body height contrast in the ROI analysis. A significantly higher activation for the control condition than for comparison was only observed in left and right inferior parietal lobule (IPL). In sum, a network of medial prefrontal, parietal and limbic areas seems to be recruited for comparison of personal characteristics.

**ROI-GLMs**

In several areas with higher activation for the comparison condition the time courses of the BOLD showed higher peaks in the intelligence than in the body height comparison condition. This indicated that, although some neural processes are common to physical and intelligence comparison, the latter may draw on additional neural resources. Therefore, in order to examine the influence of the two comparison conditions separately, we computed ROI-GLMs for all ROIs that showed a significant contrast between comparison and control conditions in the whole-brain GLM (see Table 1). For all contrasts we used a statistical threshold of $p<0.001$ (uncorrected).

**Intelligence comparison versus control condition**

Except for right PCC and one of the two ROIs in left IPL, all areas which showed significant differences in the contrast between comparison and control conditions of the whole-brain GLM also revealed a significant difference in the ROI-GLM contrast between intelligence comparison and control condition (see Fig. 3 and Table 1).

**Body height comparison versus control condition**

Relative to the control condition, body height comparison yielded a significant difference of activation of all ROIs except for one of the two ROIs in right prMFC. A significantly higher activation in the control condition was again observed in the IPL bilaterally (see Fig. 3 and Table 1).

**Intelligence versus body height comparison**

Contrasting intelligence versus body height comparison revealed significant difference of activation in left prMFC, arMFC, oMFC, APCC, left OFC, left TPJ, with higher activation for intelligence comparison in all of these areas (see Fig. 3 and Table 1). As expected these differences between the two comparison conditions include classical ToM areas.

**Discussion**

The network of brain areas that are active during person comparison seems to be different from that involved in comparisons of non-person stimuli, like numbers, or the size and luminecence of physical objects (Cohen-Kadosh et al., 2005; Pinel et al., 2004), which mainly comprises parietal and dorsomedial prefrontal areas. Conversely, the present tasks of person comparison were accompanied by activation in several medial frontal, orbitofrontal and limbic areas and the TPJ. The activation of this network was largely driven by the comparison of mental characteristics (intelligence), with activation being significantly higher for intelligence than height comparison in several areas in MFC. As expected, there was a striking overlap between the person comparison network and that commonly described for classic ToM tasks.

The difference between the activation pattern in the present person comparison tasks and that observed during size comparisons of inanimate objects may at first seem surprising, because both classes of comparisons can be conceptualised as judgments of magnitudes (numerical values of intelligence quotients or height in the case of the person comparisons). However, both our person comparison tasks differed from standard physical and numerical comparison tasks in two main respects. First, participants had to draw on their knowledge about the celebrity in question because they would have been unlikely specifically to have thought about their height or intelligence before. Second, they could not be certain of the right answer. We would propose that the second characteristic of the task constituted a similarity to other tasks where participants have to make an active decision under uncertain conditions, whereas the first contributed to the engagement of areas involved in perspective taking and ToM.

Several studies of decision making processes in ambiguous or otherwise uncertain situations have described activation of several of the medial frontal and orbitofrontal areas activated by our comparison tasks, including prMFC, arMFC, oMFC, OFC (Manes et al., 2002; Bechara et al., 2000; Fellowes and Farah, 2007; Haynes et al., 2007). OFC has traditionally been implicated in reward and punishment tasks (Rolls, 1996). Amodio and Frith (2006) suggest that the OFC guides behaviour in terms of the value of possible outcomes. Considering the processes participants had to engage in when solving the comparison tasks, it makes sense for areas that get typically involved when facts and arguments are generated, retrieved, weighed and integrated to be activated. In fact, process models of comparison (Mussweiler, 2003) have emphasized that comparison and decision making involve similar psychological processes. The brain activation pattern observed here provides converging evidence for the procedural similarity between comparison and decision making mechanisms.

In accordance with our hypothesis, we found most of the areas that constitute the classical brain network for ToM tasks to be activated during the comparison tasks. These included the TPJ bilaterally and the anterior paracingulate and dorsomedial prefrontal cortex (Baron-Cohen et al., 1999; Berthoz et al., 2002; Brunet et al., 2000; Calarge et al., 2003; Calder et al., 2002; Castelli et al., 2000; Fletcher et al., 1995; Gallagher et al., 2000; Gallagher et al., 2002; McCabe et al., 2001; Saxe and Kanwisher, 2003; Vogele et al., 2001; Walter et al., 2004). ToM research so far has demonstrated that people are most likely to mentalize in situations in which their own outcomes depend on other intentional agents (Gallagher et al., 2002; Rilling et al., 2004). Our paradigm is different in that person targets are only mentioned via their
We did not find comparison-specific activation in the region around the posterior superior temporal sulcus (pSTS), which is a key component of the putative ToM network. Recent research has implicated the pSTS in the understanding of intentional actions (Pelphrey et al., 2004; Schultz et al. 2004; Saxe et al., 2004, Zacks et al., 2001), the interpretation of goal-directed movements of a human body (Grosbras and Paus, 2006) and the indirect observation of the effects actions (Ramnani and Miall, 2004). However, we did find activity in TPJ, which seems to be selective for attributions of mental states (Saxe and Kanwisher, 2003; Saxe and Powell, 2006). Damage in TPJ causes selective deficits in judging the contents of others’ beliefs (Samson et al., 2004). In a study of personal characteristic, Mitchell et al. (2002) found activation in TPJ for the person judgments “assertive, energetic, nervous” but not for object judgments. The reason that we see activation of TPJ, but not STS, thus seems to be that participants made attributions of mental states, but there was no element of comprehension of goal-directed actions where the recruitment of pSTS would have been fundamental.

We found different amounts of activation of the ToM network for comparisons of psychological characteristics (intelligence) versus physical characteristics (body height). When comparing two people concerning their intelligence, for example, participants have to understand other people’s behaviour in terms of their mental states, that is, they have to mentalize. This is the case because judgments about psychological characteristics are inherently subjective. The intelligence of a person, for example, cannot be read off directly. Rather, it has to be inferred from the behaviors and utterances of this person. Conversely, comparisons of physical characteristics of a person are more similar to judging inanimate objects (Mitchell et al., 2002), and accordingly we found less activity in ToM relevant areas in the body height comparison condition, particularly in posterior parietal cortex (ppFC). The neural network involved in person comparisons thus appears to vary depending on the amount of ToM required for the dimension of comparison. This finding is also consistent with recent evidence demonstrating that MFC is specifically involved in judgments about psychological states (Mitchell et al., 2005).

Our behavioural data can also be tentatively interpreted as being consistent with the assumption that person judgments about psychological characteristics involve more mentalizing activities. Specifically, the fact that judgments about psychological characteristics of others took longer than judgments about their physical characteristics may be attributed to the added cognitive effort that mentalizing entails. Clearly, however, a variety of other psychological mechanisms may also contribute to this difference in processing time. For example, it has been demonstrated that people tend to define psychological characteristics in a self-serving manner (Dunning and McElwee, 1995). In the present context, this implies that participants may have given particular weight to their own strengths when constructing the definition of intelligence that builds the basis for their judgments of others. More generally, ascribing a psychological characteristic to a person requires sophisticated attribution processes concerning the links between behavioural manifestations and potential causes (Kelley, 1973). This is not the case for physical characteristics, which can be read off more readily. As is true for mentalizing, such self-serving constructions of the critical characteristic as well as such attribution processes require extra cognitive effort which ultimately leads to longer processing times. In light of this ambiguity, our behavioural data should only be interpreted in conjunction with the fMRI data.

The bilateral IPL was the only region with higher activation in the control condition. IPL activity has consistently been implicated in semantic categorization, which is the core cognitive process required in the control task. However, many of the other areas found in the literature for semantic categorization (Devlin et al., 2002, Grossman et al., 2002, Koenig et al., 2005) were not differentially activated, probably because the comparison tasks, as well, required some amount of semantic categorization.

The present findings have interesting implications for psychological research on social cognition and social judgment. It has often been assumed that comparisons on all levels of complexity involve similar psychological mechanisms (Kahneman and Miller, 1986; Mussweiler, 2003). The present findings, however, suggest that comparison activities may be more multifaceted. First, person and non-person comparisons appear to involve different neural activation patterns and hence probably different psychological processes. Second, person comparisons along psychological vs. physical dimensions involve different levels of perspective taking. These findings suggest that a more detailed analysis of the psychological mechanisms that underlie comparisons may be required. In principle, this analysis may lead to one of two conclusions. One possibility is that different types of comparison involve the same core mechanism of knowledge activation that has been identified in previous research (Mussweiler, 2003), but this mechanism is supplemented by different comparison-specific mechanisms (e.g., mentalizing). Alternatively, no such common ground may be found to exist, such that different psychological processes underlie different types of comparison (e.g. on vs. non-person comparisons).

One possible limitation of the present design is that we did not independently manipulate comparison and mentalizing requirements. However, a great deal of evidence demonstrates the ubiquity and inevitability of comparison processes in social judgments (e.g., Dunning and Hayes, 1996; Gilbert et al., 1995; Mussweiler et al., 2004). This suggests that a control condition requiring mentalizing but no comparison is impossible to construct. If two processes cannot be dissociated on theoretical grounds, a design like the present with a graded manipulation of the function in question, the mentalizing requirement in person comparison, is appropriate and still allows for the isolation of the specific effects of the manipulated function.

The present research explored the neural substrates of person comparison — one of the most basic psychological tools that are used to judge ourselves and others. The considerable overlap between the activated areas and the networks commonly observed for ToM (medial prefrontal areas and TPJ) and emotion- and value-based decision making (OFC, limbic areas) was the key finding of this study. Within the limitations of reverse inference (Pollock, 2006), this finding suggests that person comparisons involve...
perspective taking, especially when psychological dimensions are involved.

References


