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Shared Neural Mechanisms of Identity for Self, Other, and Object

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An abstract of
A thesis submitted to the Faculty of the
James T. Laney School of Graduate Studies of Emory University
in partial fulfillment of the requirements for the degree of
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Abstract

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Various theories have posited the existence of a core self process in the human brain, a constantly regenerated mental representation of first-person experience. Core self is related to the much studied self-concept, but is distinct from the self-concept in that it exists independently of conceptual knowledge. Here, we sought to elucidate the core self process using functional magnetic resonance imaging (fMRI). More generally, we sought to explain how the human brain represents identities for the self, for other human beings, and for inanimate objects. Twelve volunteers from the Emory University community underwent hour-long fMRI scans while performing a simple task. Participants were presented with one of three individuals (themselves, American icon Oprah Winfrey, and an historical racecar called the Blue Flame) and asked whether various properties applied to the individual in question. Results were inconclusive regarding core self, but indicated a widely distributed network for processing identity. Intriguingly, this network was similarly activated for all three individuals, indicating a shared neural resource for representing identities for the self, for other human beings, and for inanimate objects.

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Introduction

Background

Among the most striking elements of the human experience, and perhaps the one that most uniquely defines it, is the sense of self. Descartes' "*cogito ergo sum"* gave voice to the highly intuitive notion that thoughts, feelings, and perceptions do not exist in isolation: there must be a thinker, a feeler, and a perceiver. Descartes' argument is admittedly flawed: he presupposes the existence of "I" in the antecedent, and concludes the existence of "I" in the consequent. The inherent circularity of the famous dictum weakens the argument, but highlights its centrality in human sentience – it is monstrously difficult to imagine cognition without a self.

Nature of the Self

As inextricable as the self seems from human experience, it is notoriously elusive. Descartes abandoned the idea of a material self (Descartes, 1998), while Buddhist philosophies deny the existence of a true self entirely (Varela et al., 1993). Our aim was towards an elucidation of the processes underlying the self, by grounding the self in the biological human brain. Here, the objective of our inquiry was the core self: those neurological processes sufficient for first-person experience.

The Self-concept

One psychological viewpoint is that the self is conceptualized in the brain as a set of self-relevant "images, schemas, conceptions, prototypes, theories, goals, or tasks" (Markus & Wurf, 1987). This self-concept is grounded in knowledge about the self, and in fact may be generated by the acquisition of such knowledge. An important component of the current study was to determine the appropriate role for self-knowledge in a neural implementation of the self.

The self-concept is not only a store of knowledge, but is an entity capable of regulating behavior. For example, expectations of personal efficacy may determine the "actions that a person attempts, the effort expended at them, the persistence in the face of failure, and the thoughts and feelings experienced while engaging in behavior". Furthermore, while needs and impulses may originate outside the cognitive realm, the criteria for their satisfaction depend on a person's self-conceptions (Markus & Wurf, 1987).

Components of the self-concept are diverse. The various self-representations that comprise the self-concept may pertain to present experience, or they may reflect hypothetical renderings of what the self once was, should be, or would like to be (Markus & Wurf, 1987; Higgins, 1987). Crucially, the self-concept is not a stable, unitary entity: it is dynamically instantiated in a manner dependent on context. This means that only a small subset of the self-representations that make up the self-concept are simultaneously accessible; the rest lie dormant at any given time (Markus & Wurf, 1987). For example, Fazio and colleagues (1981) had participants respond to questions pertaining either to introversion or extroversion. Those participants who responded to questions pertaining to extroversion later appeared to perceive themselves as more extroverted than did those who responded to questions pertaining to introversion. It seems reasonable to infer that the interview phase of the study primed participants to make disparate self-representations cognitively accessible from within their general self-concepts during the testing phase.

The Core Self

It has been posited that there exists a core self, a neural process of first-person experience that is highly interactive with, but ontologically distinguishable from, the symbolic knowledge that constitutes the self-concept. Damasio (1999) presented a working theoretical and neurological framework by arguing that the self is intimately connected with consciousness. He began by describing what he calls the proto-self, "a coherent collection of neural patterns which map, moment by moment, the physical state of the organism in its many dimensions". The proto-self does not contribute directly to a conscious sense of self: it is a neural representation of the instantaneous state of the body, an afferent flow of information aptly termed "somatosensory signaling". This includes interoception, the monitoring of the chemical and thermal status of the body; proprioception, the monitoring of the positioning of the skeletal muscles; and the sense of touch, that is, temporally precise information about "texture, form, weight, and temperature" (Damasio, 1999).

According to Damasio, the proto-self is not a conscious sense of self, as the information it contains is disjoint from both memory and cognitive reflection. What Damasio believes becomes conscious is what he called the "core self", namely, a second-order representation of the proto-self engaged in a relationship with what he loosely refers to as an "object", which could be an entity in the environment, a memory, or an external or internal event. Whenever the proto-self is modified by one of these non-self objects, a mental representation of this relationship changing over time is constructed, with the representation of this change constituting the core self evolving over time. As objects constantly modify the proto-self, second-order representations of those interactions are generated continually. Therefore, the core self has an almost paradoxically dual nature: it is a transient representation of moment-to-moment, interactive existence of the self, yet it is also ever-present, serving as a consistent protagonist of the life story.

As the core self is constantly regenerated, each instance leaves a mnemonic trace on the brain: a memory of an object interacting with the self. These traces, in aggregate, form a body of conceptual knowledge that is referred to as autobiographical memory. They form the basis for our sense of identity and personhood. Samples of autobiographical memory, dynamically reconstructed as needed, constitute a third type of self: the autobiographical self. The autobiographical self, though malleable, is not transient as the core self is. It forms a backdrop for the continuous narrative of a healthy human life (Damasio, 1999).

Representing the self-other relationship in a sophisticated way, and using this representation to update knowledge about the self and the object, is the purview of widely disparate brain areas. To be a candidate for the neural substrate of the core self, any brain region must be an informational hub, wherein signals from all over the brain converge to be integrated and interpreted. Damasio implicated the anterior and posterior cingulate cortices, and we agree. We disagree, however, with his inclusion of the thalamus and superior colliculi in a hypothesized network subserving core self. These areas, though widely connected to sensory cortex, are not likely involved in the high-level interpretational process constituting core self. Interestingly, Damasio excluded the ventromedial prefrontal cortex, citing the apparently preserved core self of patients with damage to this area (Damasio, 1999).

The Search for the Self: Focusing on Self-referential Processing

Most previous research has not adopted the core vs. conceptual self distinction, but has generally approached self as a single unitary construct. Until now, the search for the neurological basis of the self largely focuses on self-referential processing. Northoff and colleagues defined as self-referential those processes that concern “stimuli that are experienced as strongly related to one’s own person”. They also noted that whether a stimulus is self-referential depends on the context and upon the individual experiencing it; there is nothing intrinsically self-referential about any given stimulus (Northoff et al., 1996; Northoff & Bermpohl, 2004). Neuroimaging studies of self-related processing have revealed a relatively consistent network in the brain, including medial prefrontal cortex (particularly ventral and orbitofrontal areas), posterior cingulate cortex and precuneus, the temporoparietal junction, and temporal poles (Northoff et al., 1996; Legrand & Ruby, 2009). We invite you to compare this network with that proposed by Damasio (1999). For the sake of continuity with previous work, we use the term “E-network” to describe the neural system implicated in, but not restricted to, self-referential processing (Legrand & Ruby, 2009).

Self-referential processing can occur in various domains. For example, spatial processing can be self-referential if carried out from an egocentric perspective, that is, if the mental spatial maps employed use the self as a frame of reference. In the facial processing domain, recognizing one’s own face, as opposed to others’ faces, can also be considered self-referential. Other cognitive domains where self-referential processing is possible include emotion, memory, motor processing, social cognition, and language. Although the specific patterns of neural activation revealed by tasks within these cognitive domains vary somewhat, the regions in the E-network are recruited in self-referential processing across domains (Northoff et al., 1996).

Previous work indicates that the E-network is critical for self-referential processing. But is it *specific* to self-referential processing? E-network regions are implicated in numerous cognitive functions, including inference, mind reading, and memory. Legrand and Ruby (2009) proposed that the E-network is responsible for a broad set of cognitive processes they called “evaluation” (hence the “E” in E-network), characterized in large part by inferences based on episodic memory. They argued that various types of evaluative processes are differentially employed for different tasks, resulting in significant contrasts between processes that are self-related and those that are not. In other words, the E-network is crucial for self-referential processes, and is sometimes preferentially activated for self-referential processes, but is not a module for self-referential processing, given that it is also highly active during processing of other people and inanimate entities and events as well.

Legrand and Ruby (2009) attribute a wide range of cognitive functions to the E-network, including some that we believe are better ascribed to different neural systems. For example, recalling items from memory, and performing logical reasoning on these items, are more the purview of lateral prefrontal regions than the medial regions included in the E-network (Thompson-Schill et al., 1997; Wagner et al., 2001). While we do not agree with the breadth of the author’s claims, we do concur that there is no module in the brain for self-processing. Rather, the processes underlying the self are likely carried out in neural circuits that also carry out functions in other cognitive domains. Our claim of domain-generality is therefore motivated by, but weaker than, that proffered by Legrand and Ruby (2009).

Accepting Legrand and Ruby's rejection of a self module must lead us to one of two conclusions: first, if there is no true self, we should call off the search. Alternatively, the self lies embedded in neural circuits that may well be utilized in tasks that are not strictly self-referential. In other words, the self is not an isolated structure, but a particular process subserved by multi-purpose neural circuits. We favored this approach.

Overview and Predictions

Overview

The current study aimed to identify the brain regions involved in instantiating the core self, something that previous neuroimaging research has not attempted, to our knowledge. In addition to dissociating self-referential processing from non-self-referential processing, it is important to identify the processes underlying the core self, independent of declarative knowledge that pertains to the self and that typically is viewed as lying in the self-concept and autobiographical self.

To this end, the experiment consisted of two tasks conducted in an fMRI scanner. In the "Main Task", participants were presented with an *individual* and a *property* (see Table 1), displayed as one or more printed words on a computer screen, and were asked to rate how well the property applied to the individual. The three possible responses were "applies poorly", "applies somewhat", and "applies well". By requiring a judgment of relevance from the participant, we ensured that the participant engaged in deep conceptual processing, as opposed to shallow perceptual processing. On some trials, no property was given. These catch trials allowed the deconvolution of the hemodynamic response to the individuals from the hemodynamic response to the properties (Ollinger et al., 2001).

[INSERT TABLE 1 HERE]

On some trials associated with the first task, the stimulus “I” represented the self, that is, the participant. On being presented with “I”, participants were asked to think about themselves in preparation for the presentation of the accompanying property. We assumed that “I” served to activate the core self, and that the subsequent property that followed and that needed to be verified activated part of the conceptual self, which became the working self.

On other trials associated with the first task, the stimulus “Oprah” represented the famous pop culture personality Oprah Winfrey. Prior to scanning, participants read a roughly 300-word biography about Oprah Winfrey (see Appendix 1). When presented with “Oprah”, participants were asked to think about the real person Oprah Winfrey in preparation for the presentation of the accompanying property. Thus, “Oprah” served to engender a conceptualization of a person who is not the core self. The resulting activation was subtracted from the activation for “I” to reveal areas associated with the core self that are distinct from conceptualizations of people in general.

On the remaining trials associated with the first task, the stimulus “Flame” represented the historical racecar known as the Blue Flame. Prior to scanning, participants read a roughly 300-word history about the Blue Flame (see Appendix 2). When presented with “Flame”, participants were asked to think deeply about the actual car in preparation for the accompanying property. “Flame” served to engender a conceptualization of an individual that is not a person. The resulting activation was subtracted from the activations for “I” and “Oprah” in order to reveal core self information for living people that is distinct from conceptualizations of individuals in general, including non-humans. Thus, by comparing processing for the self (“I”) versus processing for others (“Oprah”) and objects (“Flame”), we hoped to isolate the neural circuits responsible for processing the core self.

A second task, that we refer to as the “Baseline Task”, served as the baseline for the fMRI data analysis. We opted not to use the resting state as a baseline because BOLD activation in several of our regions of interest remains high under resting conditions (Northoff & Bermpohl, 2004; Raichle, MacLeod, Snyder, Powers, Gusnard, & Shulman, 2001). Using the resting state as a baseline would therefore eliminate important neural structures. Instead, we used an active baseline task. In this task, participants simply responded with a button press when they detected a short tone during fixation between trials of the Main Task. Because this task was active and auditory in nature, as opposed to passive and self-oriented, we anticipated a wide disparity between the BOLD response during this task and the BOLD response during the main task, and consequently a high functional signal-to-noise ratio.

Although the individuals (I, Oprah, Flame) were the main variable of interest, we also examined the BOLD response to the properties that followed the individuals. Because the properties were carefully counterbalanced according to several criteria, they allowed for analyses along several interesting dimensions. First, we compared properties that apply to humans (“I”, and “Oprah”) with those that apply to objects (“Flame”). Human-related properties were further subdivided into those that had been applied to the self (“I”) vs. those applied to the other (“Oprah”). We also compared abstract properties (such as “luxury”) with concrete properties (such as “rumbling”).

Predictions

Self-relevance for individuals. As just mentioned, we isolated neural activation associated with the participant’s core self by subtracting activation for “Oprah” and/or “Flame” trials from “I” trials during the presentation of individuals, after deconvolving (i.e., removing) activations for properties. Most importantly, and contrary to Damasio (1999), we anticipated that core self would activate the anterior cingulate and ventromedial prefrontal cortices. These regions are involved in self-related processes that would qualify as core self per se, as opposed to self-related conceptual processes. For example, the anterior cingulate is responsible for monitoring the environment for self-relevant stimuli, and the ventromedial prefrontal cortex represents stimuli that have been labeled as self-relevant (Northoff & Bermpohl, 2004). In addition to the anterior cingulate and ventromedial prefrontal cortices, we expected core self processing to activate insula, nucleus accumbens, and amygdala, as these regions together form a circuit thought to subserve top-down monitoring of self-relevance (Schmitz & Johnson, 2007).

Conversely, we anticipated that processing of the properties would result in activation throughout the E-network described above (including the precuneus and posterior cingulate cortex, the temporal poles, and the temporoparietal junction). Schmitz and Johnson (2007) reported that the mPFC and PCC activate during introspective processes such as self-appraisal of one’s traits, opinions, morals, and attitudes. We expected that processing of the non-self person (“Oprah”) would recruit this network as well, owing to the frequent overlap between self and other in neuroimaging studies (Legrand & Ruby, 2009). Furthermore, we predicted that medial prefrontal activation would be more dorsal for these trials than for self trials, based on similar results from Mitchell et al. (2005) and a metanalysis by van Overwalle (2009).

Individuals: Humans vs. objects. We expected that the difference between processing humans vs. objects would manifest most strongly in regions previously associated with one or the other. For example, the extrastriate body area and fusiform face area would be selective for humans, whereas motor areas implicated in veridical and imagined interaction with objects would be selective for objects (Jeannerod, 1994). In this particular case, we speculated that properties relevant to the Blue Flame would recruit motor and premotor areas involved with driving a car, occipitotemporal areas involved with perceiving it visually, or superior temporal regions involved with hearing its engine.

Properties: Concrete vs. abstract. We anticipated that processing concrete as opposed to abstract properties would result in increased activation in the brain's modal systems. Concrete concepts are thought to be represented by the same neural circuits used to process them during "perception, action, and introspection" (Barsalou, Santos, Simmons, & Wilson, 2007). For example, "wheezing" was expected to recruit the motor systems that would be enlisted in the act of wheezing, as well as the auditory systems that would be used to perceive the sounds of a person wheezing.

Abstract concepts are thought to be more complex, and their representation in the brain is thought to involve more introspective content than concrete concepts (Barsalou & Weimer-Hastings, 2005). Therefore, we expected abstract properties to recruit cortical midline structures involved in introspective and evaluative processes, particularly the ventral and dorsal medial prefrontal cortices (Northoff & Bermpohl, 2004). If the property in question possessed affectively valenced qualities, particularly with respect to reward, neural activation might include the more lateral orbitofrontal cortices (O'Doherty, Kringelbach, Rolls, Hornak, & Andrews, 2001).

Methods

Design and Participants

The experiment consisted of a training session immediately followed by an fMRI scanning session. In the training session, participants were familiarized with Oprah and the Blue Flame. They then received instructions for the Main Task and Baseline Task and completed a practice run on a desktop computer, otherwise identical to the runs they would perform in the scanner. In the scanning session, participants received 270 trials, of which 180 were complete trials and 90 were catch trials. The catch trials constituted 33% of the total trials, a proportion in the recommended range for an effective catch trial design (Ollinger et al., 2001). The trials were distributed across 6 runs, each of which lasted 7.5 minutes. In each run, the critical trials and catch trials were ordered in an event-related design according to one of 6 sequences selected out of 100,000 as optimal by the optseq2 algorithm (http://surfer.nmr.mgh.harvard.edu/optseq). Instances of the Main Task were separated by ISIs varying randomly between 3 and 12 sec long in multiples of 3 (M = 3.53, SD = 1.47).

Each individual ("I", "Oprah", or "Flame") was presented 15 times per run for 3 sec (see Table 3), for a total of 75 presentations across the 6 runs. Each individual represents a condition in the later analysis. There were also 6 conditions associated with the properties: properties were either abstract or concrete, and they were crossed with either “I”, “Oprah”, or “Flame”. The assignment of the different individuals and property types to trials was random, not blocked. Therefore, on a given trial, the participant could not predict either the individual or the property type.

Twelve right-handed, native English speakers with normal hearing and normal or corrected vision were recruited from the Emory community. Of these, 6 were male and 6 were female, with a mean age of 23.5 yr (SD = 6.69). Two additional participants were excluded from analysis due to extreme head motion in the scanner or failure to adequately perform the task. Participants received $50 and images from their anatomical scans.

Materials

All stimuli on the primary task consisted of words or short phrases presented in the center of the screen. Fixation was a white cross on a black background with no border.

Individuals. Individuals were presented to participants as single words, white text against a black background in 18 point Georgia font. To ensure that gaze remained consistent, with a constant angle of view, all words or phrases, for either individuals or properties, were surrounded by a white border of fixed size. Three individuals were used: “I”, “Oprah”, and “Flame”. Prior to scanning, participants were instructed in detail as to what each of these words represented, so that during scanning, they were able to conceptualize the correct individual deeply, and to predicate the corresponding property upon it.

Properties. Much like the individuals, properties were presented to participants as typed words in white 18-point Georgia font on a black screen, surrounded by the same white border. Each property was assigned to one of four categories according to two distinctions: whether it represented an abstract property or a concrete one, and whether it was apropos for humans (the same set of properties was used for “Oprah” and “I”) or cars (such as the Blue Flame). A total of 120 different properties were used, counterbalanced for word length, number of words, part of speech, and a distinction we call “sub-category”, as described next.

The sub-categories assigned to properties differed depending on concreteness. Whereas concrete properties were designated as Visuo-spatial, Auditory, or Motor/Body, abstract properties were designated as being related to conscientiousness, agreeableness, or openness to experience: three dimensions of the Big Five personality space (McCrae & Costa, 2003). An equal number of properties for each sub-category were used within the larger sets of concrete vs. abstract properties.

Sub-categories for concrete properties were relatively straightforward, and pertained largely to the sensory modality used in judgments regarding those properties. Visuo-spatial properties were those that could be apprised according to simple visual or spatial criteria. For example, we used “shiny” and “roomy” for cars (i.e. “Flame”), and “tall” and “long arms” for humans (i.e. “I” or “Oprah”). Auditory properties were those that could be apprised according to simple auditory criteria. For example, we used “noiseless” and “blaring horn” for cars, and “soft voice” and “giggling” for humans. Motor/Body properties were those that related to physical structure or motion. For example, we used “aerodynamic” and “strong brakes” for cars”, and “good posture” and “nimble” for humans.

Sub-categories for abstract properties were subtler. We derived them from McCrae and Costa (2003), a study of human personality and its variable characteristics. Conscientiousness referred to such traits as ethical behavior, responsibility, and dependability. For example, we used “powerful performance” and “security” for cars, and “self-discipline” and “rational” for humans. Agreeableness referred to such traits as sympathy, compassion, amicability, and generosity. For example, we used “luxury” and “beautiful” for cars, and “friendly” and “eager to please” for humans. Openness to experience referred to such traits as nonconformity, adventurousness, and rebelliousness. For example, we used “ruggedness” and “innovative” for cars, and “vivid imagination” and “spontaneity” for humans.

Note that while the four categories (human vs. object and abstract vs. concrete) constituted an experimental manipulation, the sub-categories as described above were used solely as a counterbalancing measure; this was not an experimental manipulation, given that there are insufficient trials to achieve sufficient power in BOLD signal contrasts.

In all, we chose 120 properties: each of four categories (object-concrete, object-abstract, human-concrete, and human-abstract) was divided into three sub-categories as described above. For each of these twelve sub-categories, we chose ten properties (see Table 2).

[INSERT TABLE 2 HERE]

Tone. The tone used in the Baseline Task was a pleasant synthetic orchestral string sound. It was a C-Major chord comprised of C2, E2, G2, and C3 that persisted for 500 milliseconds with natural-sounding attack and release.

Procedure

Structure of a trial. Any complete trial of the Main Task lasted for 6 seconds, not including a variable intertrial interval. First, an individual ("I", "Oprah", or "Flame") was presented for 3 seconds. Participants were instructed to think about the individual in order to prepare for the presentation of the property. Second, the property was presented for 3 seconds. During the property presentation, participants were instructed to answer the question "How well does the property apply to the individual?" using one of three buttons on the fMRI button box (see Figure 1).

In between trials, participants fixated on a small white cross in the center of the black screen. For the duration of this intertrial interval, participants were instructed to remain vigilant for a tone, to which they responded with a button press upon hearing it. The tone occurred once during every intertrial interval, but the time of onset varied randomly from 500 milliseconds after the end of the previous trial to 1500 milliseconds before the start of the subsequent trial. This procedure constituted the Baseline Task.

On some trials, the presentation of the property was omitted. These were called "catch trials", and their inclusion in the experimental design permitted deconvolution of the BOLD responses to individuals from those for properties. In a catch trial, the participant was not asked to make a response; the presentation of the individual was immediately followed by a return to the Baseline Task. As mentioned before, trials that include both an individual and a property were called complete trials, while those including only an individual were called catch trials.

[INSERT FIGURE 1 HERE]

Structure of the experiment. In the training session, participants provided informed consent and were screened for a battery of potential problems that could arise during a magnetic resonance scan. They then received background information on Oprah Winfrey and the Blue Flame, and read it carefully so as to become familiar with these individuals. The descriptions were roughly 300 words each and included color pictures (see Appendices 1 and 2).

Participants received detailed instructions for the Main Task and Baseline Task on a personal computer running an interactive E-Prime script. During these instructions and the subsequent practice run, participant used an E-Prime button box to practice making responses. In the scanner, participants would use a Current Designs fiber optic button box designed for high magnetic field environments. Using "I", "Oprah", and "Flame", and properties similar to but different from those actually used in the experiment, participants were incrementally acclimated to the paradigm. Specifically, participants successively received practice on the Main Task, the Main Task with catch trials, the Baseline Task, and finally all tasks and trial types together. The experimenter was present in the room to answer questions, which were rarely though sometimes asked. Besides imparting the details of the paradigm, instructions emphasized the importance of thinking about the individual as soon as it was presented, as opposed to waiting for the property.

Next, at the same computer, participants performed a full practice run of 30 complete trials and 15 catch trials. Again, the properties received were similar to but different from those that would be used in the actual experiment. The experimenter was not present in the room. When the participant emerged about 8 minutes later, he or she was asked to confirm that he or she understood the task and was ready to perform it in the scanner.

Following the practice run, the experimenter and the participant walked 5 min across campus to the scanner. Once settled safely and comfortably in the scanner, an initial anatomical scan was performed, followed by the 6 critical functional runs. Finally, a second anatomical scan was taken when time permitted. The second anatomical scan was omitted for none of the participants whose data was included. In each functional run, participants received 30 complete trials and 15 catch trials. Both types of trials (complete and catch) were randomly intermixed as described before. On a given trials, participants could not predict whether a complete trial or a catch trial was coming, a necessary condition for an effective catch trial design (Ollinger et al., 2001). Random ISI occurred between trials ranging from 3 to 12 sec (in increments of 3 sec). Each individual occurred 15 times, followed 10 times by a property and 5 times by a return to fixation. Total time in the scanner was approximately 1.25 hours.

[INSERT TABLE 3 HERE]

Image Acquisition

The neuroimaging data were collected in the Biomedical Imaging Technology Center at Emory University on a research-dedicated 3T Siemens Trio scanner. In each functional run, 155 T2*-weighted echo planar image volumes depicting BOLD contrast were collected using a Siemens 12-channel head coil and parallel imaging with an iPAT acceleration factor of 2. Each volume was collected using a scan sequence that had the following parameters: 56 contiguous 2 mm slices in the axial plane, interleaved slice acquisition, TR = 3000 ms, TE = 30 ms, flip angle = 90°, bandwidth = 2442 Hz/Px, FOV = 220 mm, matrix = 64, voxel size = 3.4 mm × 3.4 mm × 2.0 mm. This scanning sequence was selected after testing a variety of sequences for susceptibility artifacts in orbitofrontal cortex, amygdala, and the temporal poles. We selected this sequence not only because it minimized susceptibility artifacts by using thin slices and parallel imaging, but also because using 3.4 mm in the X-Y dimensions yielded a voxel volume large enough to produce a satisfactory temporal signal-to-noise ratio.

In each of the two anatomical runs, 176 T1-weighted volumes were collected using a high resolution MPRAGE scan sequence that had the following parameters: 192 contiguous slices in the sagittal plane, single-shot acquisition, TR = 2300 ms, TE = 3.02 ms, flip angle = 8°, FOV = 256 mm, matrix = 256, bandwidth = 130 Hz/Px, voxel size = 1.0 mm × 1.0 mm × 1.0 mm.

Image Preprocessing

Image preprocessing and statistical analysis were conducted in AFNI (Cox, 1996). The first anatomical scan was registered to the second, and the average of the two scans was computed to create a single high-quality anatomical image. Slice-time correction was performed on the functional volumes followed by motion correction and transformation to Talairach space, which were performed in a single step to reduce error that occurs when the functional data are independently warped multiple times. A transformation matrix for motion correction was generated in which all functional volumes were registered to a volume near the end of the final run. To generate the Talairach transformation matrix, the averaged anatomical image was skull-stripped and aligned to the same functional volume used as the registration base for motion correction. Voxels outside the brain were removed from further analysis, as were high-variability low-intensity voxels likely to be shifting in and out of the brain as a result of minor head motion. The anatomical image was then transformed to Talairach space using an automated procedure employing the TT_N27 template (also known as the Colin brain, an averaged dataset from one person scanned 27 times). The matrices generated from the Talairach transformation of the anatomical dataset were concatenated with the motion correction matrix and applied in a single step to the functional volumes. At this point, the voxel dimensions of the functional volumes were also resampled from 3.4 mm × 3.4 mm × 2.0 mm to 3.0 × 3.0 × 3.0 mm. The functional data were next smoothed using an isotropic 6 mm full-width-half-maximum Gaussian kernel. Finally, the signal intensities in each volume were divided by the mean signal value for the respective run and multiplied by 100 to produce percent signal change from the run mean. All later analyses were performed on the percent signal change data. In all later regressions, the six regressors obtained from motion correction during preprocessing were included to remove any residual signal changes correlated with movement (translation in the X, Y, and Z planes; rotation around the X, Y, and Z axes). Scanner drift was removed by finding the best-fitting polynomial function correlated with time in the preprocessed time course data.

Data Analysis

Regression analysis was performed at the individual level using a canonical, fixed-shape gamma function to model the hemodynamic response. Betas were calculated from event onsets of 9 conditions. The easiest way to think of them is as a 3 x 3 matrix. Consider Table 1 above, with example stimuli given for each of the 9 conditions. The 3 individuals each constituted a condition (I, Oprah, and Flame), as did the abstract and concrete properties associated with each (Abstract/I, Concrete/I, Abstract/Oprah, Concrete/Oprah, Abstract/Flame, and Concrete/Flame). Note that the set of properties associated with "I" and with "Oprah" were identical: each was used once with each human individual, and therefore contributed once to each of two conditions (one for "I" and one for "Oprah").

As described earlier, the catch trial design allowed us to separate activations for the individuals from activations for the subsequent properties that followed immediately without random jitter. The three individual conditions were modeled by creating regressors that included individual presentations from both complete trials and catch trials. Including individuals from both trial types in one regressor made it possible to mathematically separate each individual from the subsequent property condition. Thus, activations from the preceding individual blocks were not included in the activations for the six property conditions, having been removed by separating out the three individual conditions.

The beta coefficients for the nine conditions from each participant's regression were entered into group analyses using a general linear model. A voxel-wise significance level of $p < .005$ with a spatial extent threshold of 999 mm^3 (37 functional voxels) was used to threshold the resulting effects, yielding a whole-brain threshold of

$p < .05$ corrected for multiple comparisons. The spatial extent threshold was established using ClustSim in AFNI, which runs Monte Carlo simulations to estimate extent thresholds needed to exceed cluster sizes of false positives at a given voxel-wise threshold. Clusters as small as 270 mm^3 (10 functional voxels) are also presented for completeness, given that we only have 12 participants at this stage of the experiment.

Originally, two clusters in one particular contrast (Individuals > Properties) were quite large, spanning many brain regions known to be functionally heterogeneous. Interpreting these larger clusters as unitary foci of activation was not optimal given the many diverse functional regions that they contained. To parse large clusters into more meaningful components, we used the AFNI Talairach atlas to identify more specific anatomical regions within large clusters. We then extracted the signal change from activations in each nested anatomical region using masks. Thus, this procedure allowed us to examine average differences among conditions across voxels in distinct regions known to differ in function (instead of examining averages across voxels spanning many regions in the initial large clusters). We chose to primarily use Talairach-defined Brodmann Area (BA) masks, but in some cases, it was more appropriate to use a defined anatomical region as a mask instead of a BA. Wherever possible, we include both names.

During the extraction process, some voxels from the large initial clusters were lost if they resided outside the Talairach-defined BA mask. These significantly active voxels generally appeared to lie outside grey matter on the template, a result of averaging, warping, and smoothing. Thus, the total number of voxels summed across extracted clusters was smaller than the total number of voxels in the original large, undifferentiated cluster. Although some voxels dropped out with use of the Talairach masks, this procedure allowed us to sample the patterns of activation across the conditions in distinct, well-defined regions of a large cluster. In the relevant table, sub-clusters extracted from the same large cluster are shown adjacently and labeled as such in Tables 9 & 10.

We planned 6 *a priori* statistical contrasts for analyzing the differences between conditions. They fell into four main categories:

Individual vs. individual. We subtracted the activation for each individual from the activation for the other individuals, in order to more clearly differentiate neural circuits responsible for processing specific types of individuals. In particular, if a network subserving core self were to be discovered, we expected to find it in the contrast between activations for "I" minus "Oprah". The "I" condition involved deep processing of the self, largely separated from the conceptual information that would be activated by the subsequent property. By then contrasting the "I" condition against the "Oprah" condition, we hoped to isolate core self processing from processing of others. In addition to I > Oprah, we also looked at I > Flame and Oprah > Flame to examine the basic processes underlying the representation of non-self humans and objects.

Abstract vs. concrete. We believed that the brain may process properties differently according to their level of abstraction. By comparing abstract vs. concrete properties across individuals, we aimed to elucidate these differences.

Human vs. object. In these contrasts, we specifically compared properties for humans (I and Oprah) with those for objects (Flame).

Individual vs. property. We subtracted the activation for properties from the activation for individuals, across all individuals and both levels of abstraction for the properties. In this way, we can learn about the shared neural substrates common to representations of the self, other people, and objects, and common to abstract and concrete properties.

Results

Contrasts Between Individuals

Contrary to our expectations, the critical contrast comparing "I" vs. "Oprah" (I – Oprah) did not reveal widespread differences (see Table 4). Especially surprising was the absence of significant activations in the E-network, or the brain stem areas suggested by Damasio, namely the neural systems where core self presumably resides. Interestingly, the brain regions where differences did appear were relatively low-level visual areas. Prominent bilateral activations for "I" in extrastriate body area (EBA) agree with previous findings (see Figure 2). The EBA, originally identified for its role in the visual perception of human bodies and body parts (Downing et al., 2001), is also implicated in integrating sensorimotor information pertaining to intentional actions (Astafiev et al., 2004). A more recent study showed that the EBA is specifically involved with an embodied sense of self (Arzy et al., 2006). In light of these findings, the activation of the EBA in the current study is consistent with Damasio's notion of a core self emerging from maps of bodily states (Damasio, 1999).

Contrasting "I" with "Flame" instead of Oprah (I – Flame) yields similarly paltry results (see Table 5). However, one additional activation, in the right temporoparietal junction (TPJ), supports our hypothesis of E-network involvement in mental representation of the self. Interestingly, both “Oprah” and “Flame”, when contrasted against “I”, revealed bilateral activations in the lingual gyrus (see Figure 2), perhaps representing the visual appearance of Oprah and the Blue Flame.

Contrasting “Oprah” with “Flame” (Oprah – Flame) and vice-versa revealed only one significant activation unique to “Oprah”, a small cluster in the left premotor cortex, located on the precentral gyrus in BA 6 (see Table 6). We find this puzzling: if anything we would have expected premotor cortex to be active for Flame, as it is involved in sensory guided motor planning. Unique to “Flame” were several small clusters in brain areas usually associated with emotion and emotional memory, including the right amygdala and bilateral caudate nuclei. These unusual activations may be attributed to the novelty of this particular stimulus, and the perhaps daunting task of answering questions about an object with which participants were not previously familiar.

Taken together, the dearth of activity in both the cortical midline and in prefrontal areas indicates that participants distinguished between individuals at a relatively superficial visual level. This is rather puzzling. We consider it unlikely that mental representations of self and others, with all of the complex qualities they possess, are limited to the regions revealed in the aforementioned contrasts. Instead, we suggest that such representations are as rich and distributed as one might expect, but that the three individuals recruit highly overlapping neural systems associated with processing identity, such that minimal differences between individuals appear. To explore this possibility, and to discover what these shared neural substrates might be, we later consider contrasts between individuals and properties. First though, to further motivate that analysis, we examine the differences between types of properties.

[INSERT FIGURE 2 HERE]

[INSERT TABLES 4 - 6 HERE]

Contrasts Between Types of Properties

Abstract vs. concrete. We assessed the brain areas active for the abstract vs. concrete properties across all three individuals together (Abstract/I + Abstract/Oprah + Abstract/Flame - Concrete/I - Concrete/Oprah - Concrete/Flame). We expected that abstract properties would elicit activity in brain regions along the cortical midline, particularly in the medial prefrontal cortices. Conversely, we expected concrete properties to be represented in the brain's modal systems for perception and action.

We were half right (see Table 7). Activation for concrete properties was distributed throughout the cortex, roughly falling into two distinct categories. First, activations were recorded in secondary sensory regions such as the left fusiform gyrus and the left insula (see Figure 3), implying a grounded representation of the concrete properties. Second, a dorsal frontoparietal network was activated (see Figure 3). This network has previously been implicated in goal-directed attention, particularly with regard to stimulus or response selection, and with the working memory required to complete selection tasks offline. Relevant areas include inferior and middle frontal gyri and inferior parietal lobule (Corbetta & Shulman, 2002; Seeley et al., 2007).

[INSERT FIGURE 3 HERE]

[INSERT TABLE 7 HERE]

Humans vs. Object. By contrasting properties for "I" and "Oprah" with those for "Flame" (Abstract/I + Concrete/I + Abstract/Oprah + Concrete/Oprah - Abstract/Flame - Concrete/Flame), we isolated brain regions responsible for representing properties as predicated of humans as opposed to objects (see Table 8). Only two clusters were significantly active for properties predicated of "Flame": one in left parahippocampal gyrus, including parts of parahippocampal cortex and perirhinal cortex, and one in the left fusiform gyrus (see Figure 4). This is not surprising, as perirhinal cortex and fusiform gyrus are involved in object recognition. Parahippocampal cortex is involved in source memory (Davachi, Mitchell, & Wagner, 2002), suggesting that participants were simulating the Blue Flame in context (see Barsalou, 2009 for a description of situated conceptualization).

Properties predicated of "I" and "Oprah" activated a much larger network (see Table 8). Most notable were robust activations along the cortical midline, including the ventromedial and dorsomedial prefrontal cortices and the posterior cingulate (see Figure 5). Both regions are commonly engaged in attributing dispositions and traits to the self and others (van Overwalle, 2009; Mitchell, Banaji, & Macrae, 2005; Legrand & Ruby, 2009; Northoff, Heinzel, de Greck, Bermpohl, Dobrowolny, & Panskepp, 2006). We looked at the two parallel contrasts specific to "I" and "Oprah" (I – Abstract/I – Concrete/I; and Oprah – Abstract/Oprah – Concrete/Oprah) post hoc. Interestingly, we did not observe the common dissociation between ventral and dorsal mPFC for self and other, respectively. As an exception, there was a small activation unique to properties for I in right ventromedial PFC.

[INSERT FIGURES 4 & 5 HERE]

[INSERT TABLE 8 HERE]

Contrasts Between Individuals and Properties

Finally, we considered contrasts between the individual and property conditions (see Tables 9 & 10). Robust activations here would demonstrate that one neural system had the capability to represent the basic identities of diverse individuals (I, Flame, and Oprah) whereas another would represent diverse properties (abstract, concrete). Furthermore, brain regions that were more active for individuals than for properties, but that were not active in individual-individual contrasts, could reasonably be inferred to comprise a shared neural substrate for representing the basic identities of individuals (see the later discussion for a more in-depth treatment of the notion of self-as-metaphor-for-other). This is precisely what we observed, as large circuits across the brain were selectively active either for individuals or for properties.

First, it is important to note that participants were not required to perform a motor action, nor to make any response of any kind, until the presentation of the property. Accordingly, we observed activations specific to properties that are likely due to the button press alone. These areas include the thalamus, midbrain, left putamen, supplementary and primary motor areas (mostly left-lateralized, contralateral to the right-handed button press), and right culmen (ipsilateral to button press).

Areas active for individuals. Areas active when participants focused on individuals (I + Oprah + Flame – Abstract/I - Abstract/Oprah - Abstract/Flame - Concrete/I - Concrete/Oprah - Concrete/Flame) fall into three broad categories. First, we observed significant activations in regions that support the notion of an embodied sense of identity. These include the previously described EBA and the posterior insula, a region functionally connected with motor and somatosensory cortices (Deen, Pitskel, & Pelphrey, 2010) and involved in mapping the physiological condition of the body and the phenomenological awareness of bodily states (Craig, 2009; 2010). Second, we observed activations throughout the E-network, including medial prefrontal cortex, posterior cingulate cortex, precuneus, and inferior parietal lobe regions including the right temporoparietal junction (see Figure 6). These areas have been identified in a variety of contexts, including self-processing (Gusnard, Akbudak, Shulman, & Raichle; Legrand & Ruby, 2009; Northoff, Heinzel, de Greck, Bermpohl, Dobrowolny, & Panskepp, 2006) and resting state intrinsic activity in the absence of an external stimulus, when attention is presumed to be focused on one's own internal mental states (Raichle, MacLeod, Snyder, Powers, Gusnard, & Shulman, 2001; Mason, Norton, Van Horn, Wegner, Grafton, & Macrae, 2007).

Third, we observed large activations at the frontal poles (see Figure 7). We suggest that this activity is not part of the neural representation of identity, but rather was specific to the particular task. Participants were instructed to think deeply about the individuals in preparation for the predication process that would usually follow (except during catch trials). The frontal poles are implicated in complex relational or analogical reasoning. They are thought to be part of a hierarchical dorsolateral prefrontal system for the "evaluation, monitoring, and manipulation" of task-relevant information (Christoff & Gabrielli, 2000). Distinctions between the frontal poles and the more caudal region known as dorsolateral prefrontal cortex (DLPFC) seem to reflect a hierarchical arrangement rather than a categorical shift in functionality. The frontal poles are associated with the processing of more complex relational structures than the DLPFC (Cho et al., 2009), and the information processed by the frontal poles tends to be internally generated, while the information processed by the DLPFC tends to be generated by an external stimulus. Interestingly, we found activation in the frontal poles for individuals and in the DLPFC for properties.

[INSERT FIGURES 6 & 7 HERE]

Areas active for properties. Areas active when participants focused on applying the properties to the individuals fall into two categories. First, we observed an enormous and robust pattern of activation, largely left lateralized, spanning the entirety of the inferior frontal gyrus (IFG), extending superiorly into the ventral-caudal aspect of the middle frontal gyrus (MFG). This region included but was not limited to the DLPFC as described earlier (see Figure 7). The precise role of the left IFG has been the subject of debate, with alternative theories suggesting subtly different functions for this region. One theory holds that left IFG subserves a selection process by which relevant semantic information is selected from amidst irrelevant information in the service of some goal. In other words, the left IFG is enlisted in conflict resolution, serving to bias competition between mental representations (Thompson-Schill, D'Esposito, Aguirre, & Farah, 1997). Another theory holds that rather than selection per se, it is increasing retrieval demands that selectively recruit the left IFG. In other words, when bottom-up associative process fail to recover the information required by a task, the left IFG is enlisted in order to access that information in a top-down, goal directed manner (Wagner, Paré-Blagoev, Clark, & Poldrack, 2001). Our data are consistent with both of these theories, in that our task required both controlled retrieval of semantic information regarding the individuals and selection of a relevant subset of that information in order to make a judgment.

Second, the property condition was associated with a plethora of sensorimotor regions, including numerous extrastriate visual areas such as the cuneus and the lingual and fusiform gyri, as well as the anterior insula. Additionally, properties activated the left precuneus, a heteromodal association area heavily involved in visuo-spatial mental imagery (Cavanna & Trimble, 2006). Again examining more specific contrasts post hoc (2*I – Abstract/I – Concrete/I; 2*Oprah – Abstract/Oprah – Concrete/Oprah; and 2*Flame – Abstract/Flame – Concrete/Flame), we noted that properties for "I" as opposed to "Oprah" or "Flame" were the main contributors to the activation we observed. If we assume that participants imagined particular individuals in a manner that reflects previous perceptual experience with those individuals, and that participants likely have had no direct personal interactions with Oprah Winfrey or with the Blue Flame, this result in unsurprising. The imagery facilitated by the precuneus is encoded in egocentric coordinates, reflecting a first person, experiential perspective. We therefore infer that participants were representing properties by simulating their sensory characteristics, utilizing the same neural systems that would subserve their perception.

[INSERT TABLES 9 & 10 HERE]

Discussion

The Neural Substrates of the Core Self

The primary purpose of the current study was to determine what, if any, are the neural substrates of subjective, first person experience. Motivated by the notion of the core self (Damasio, 1999), we set out to isolate it in the human brain. We knew it would be elusive: though continuously present, the core self would be paradoxically evanescent. Rather than being a stable entity, the core self is thought to generate the illusion of continuity through perpetual regeneration, like the frames of a film. Thus it is distinct from the self-concept: conceptual knowledge about the self, though activated selectively, and dynamically retrieved from memory based on context, is not subject to the same unending cycle of birth and death.

Therefore our task was twofold. The first logical step was to separate mental activity that was self-referential from that which was not, hence using three individuals along a gradient from most related (I) to least related (the Blue Flame) to the self. The second logical step was to winnow away the self-concept. Conceptual knowledge regarding the self is frequently if not always present in the mind, but although it serves to color first person experience with its associated beliefs, expectations, and desires, it is not synonymous with first person experience. This is why we used properties and a predication task to isolate these intriguing but irrelevant cognitive elements.

Our data lend scant evidence for a core self process. After activation for conceptual knowledge of properties was discarded, and after activation for the non-self others was removed, there was not much left to ascribe to the core self. We identified visual areas such as EBA for the self and the fusiform gyrus for others that we believe underlie an embodied sense of identity, but these areas were local. We offer three potential explanations. First, our experimental manipulation may not have been the right one to elicit the core self. One major assumption of our paradigm was that attending to the self (as "I") would selectively activate the core self process. Since core self is perpetually present, it would have to be generated to a greater or lesser extent depending on the task used in a contrast. This is a reasonable assumption, given that top-down attention modulates the hemodynamic response (Kastner, Pinsk, De Weerd, Desimone, & Ungerleider, 1999; Brefczynski & DeYoe, 1999), but not one that should be taken for granted, particularly given the complex nature of the proposed core self process.

Second, core self may not be subserved by any particular set of brain regions, but may instead emerge from a particular type of interaction between regions within relevant networks. Functional MRI measures one type of neural information processing; other types exist at different spatial and temporal scales. For example, rhythmic changes in voltage in various high-frequency bands convey information across widely dispersed cortical networks (Doesburg, Green, McDonald, & Ward, 2009). Functional MRI is not well suited for observing activity at time scales of less than one second, and much of the story of information processing in the brain happens at 40 Hz.

Finally, there may in fact be no such thing as the core self. Before weighing in on the philosophical implications regarding free will and the soul, however, it will be prudent to conduct further research. Our data are in no way conclusive on this matter.

Fundamental Processing of Identity

Numerous brain regions were more active for the presentation of the individuals than for the presentation of the properties. These included the medial prefrontal cortex, anterior and posterior cingulate cortices, precuneus, and inferior parietal lobe regions including the right temporoparietal junction, as well as areas in extrastriate cortex and the posterior insula. On the whole, activity in these regions varied little between individuals, as evidenced by the paucity of significant activations in the individual-individual contrasts. We propose that the human brain has the propensity to represent identities in a fundamental way that is not dependent on conceptual knowledge. Activations in the extrastriate body area, anterior cingulate cortex, and posterior insula suggest that this fundamental processing of identity is grounded, at least in part, in representations of the body. Activations in the E-network including mPFC and right TPJ suggest that fundamental processing of identity may also be grounded in the representation of mental states. The most intriguing implication of the data is that this mechanism for processing identity is not exclusive to the self – it is used redundantly to represent identities of other people and even of inanimate objects. Such re-use of neural structures may be the norm in the human brain, an elegant solution to limitations of space, and the computational demands posed by implementing intelligence in wetware. Novel functions emerge in systems that previously (phylogenetically speaking) served other purposes (see Anderson, 2010 for a comprehensive review). Domains in which this paradigm of redundancy is thought to be a defining principle include: symbolic conceptual processing (Barsalou, Santos, Simmons, & Wilson, 2007; Barsalou, 1999), working memory (Postle, 2006), and metal imagery (Kosslyn, Ganis, & Thompson, 2001; Halpern & Zatorre, 1999). The list goes on indefinitely.

One major difference between individuals was observed, however, and the distinction was drawn between self and non-self. The EBA was more active for “I” while bilateral lingual gyri were more active for “Oprah” and “Flame”, indicating that even fundamental identity processing may be in some way egocentric: different individuals are represented in a way that reflects first person interaction with those individuals. For the self, this means the experience of being an embodied self. For others, this means the experience of perceiving, often visually, a non-self other. It is important to note that these differences are differences in degree: both regions were activated above baseline for all three individuals, and are probably still part of the same shared neural substrate for processing identity.

Predication: Applying Properties to Individuals

The predication process appears to involve three related components. First, a frontoparietal system including the frontal poles, dorsolateral prefrontal cortex, and inferior parietal lobes retrieves and selectively attends to relevant information. This stage has less to do with the content of predication and more to do with the process of providing a structure in which it can occur: one in which the relevant conceptual and identity information networks can be activated, and the relationships among them can be evaluated.

Second, a neural representation of the relevant individual must be engendered, in the previously described identity circuit. Because such a circuit appears in the contrast of individuals vs. properties, it is clear that activation in this circuit is more robust when the individual is first presented than during the subsequent application of the property. Whether this attenuation simply reflects an adaptation of the BOLD signal over time, or a task-related attenuation of the neural representation of the individual's identity, is unknown.

Third, the conceptual information regarding the individual and the properties applied to the individual must be represented. These representations are likely perceptual in nature, as suggested by activations in such sensory areas as lingual gyrus, fusiform gyrus, cuneus, superior temporal gyrus, and insula. Activations in multimodal association areas such as the precuneus and parahippocampal gyrus suggest that conceptual representation for properties might not only be grounded in sensory systems, but situated in the contexts in which they might arise. The experimental design of the current study was not sensitive to differences between isolated and situated mental representations of properties: further study is warranted.

Conclusions

In the present study, we were unable to find support for a core self process underlying subjective first-person experience that is unique to the self. We did however discover a possible mechanism for representing identity. We showed that the proposed neural substrate was used redundantly to represent the self, a non-self other, and an inanimate object in much the same way. Furthermore, we demonstrated that this mechanism does not rely on conceptual information pertaining to those individuals, but instead captures something more basic about the individual’s identity. This fundamental identity sense is likely based on feelings of embodiment and representations of mental states.

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Tables and Figures

Table 1.
Nine stimulus types, with an example of each

	I	**Oprah**	**Flame**
Individual	I	Oprah	Flame
Concrete (property)	tall	cracks knuckles	grinding gears
Abstract (property)	open-minded	generous	well cared for

Table 2.
Categories and sub-categories of properties used as stimuli

	Object	**Human**
Concrete	(10) Conscientiousness (10) Agreeableness (10) Openness to experience	(10) Conscientiousness (10) Agreeableness (10) Openness to experience
Abstract	(10) Visuo-spatial (10) Auditory (10) Motor/body	(10) Visuo-spatial (10) Auditory (10) Motor/body

Table 3.
Nine trial types, each used five times in every run (six runs total)

	I	Oprah	Flame
Concrete	5	5	5
Abstract	5	5	5
Catch	5	5	5

Table 4.

Contrast between individuals: I > Oprah

Condition	**Brodmann area**	**Brain region**	**Cluster volume (mm^3)**	**Peak x**	**Peak y**	**Peak z**	**Mean t-value**
I	19, 37	L EBA	1,161	-49	-67	2	4.0479
I		R MTG/Mid Occ g	1,080	31	-70	20	4.0889
I		L Post MTG	324	-34	-55	8	4.3595
Oprah	18	R Lingual g	3,699	19	-85	-3	-4.3301
Oprah	18	L Lingual g	3,429	-13	-85	-6	-4.7357
Oprah	30	R Parahip g	675	19	-37	-6	-4.4896
Oprah	36	R Parahip Cortex	270	34	-28	-18	-3.9411
Oprah	30	R Cuneus	270	19	-64	8.5	-4.7163

EBA = extrastriate body area; MTG = middle temporal gyrus; Parahip = parahippocampal. Corrected p = .05 for clusters at least 999 mm^3.

Table 5.
Contrast between individuals: I > Flame

Condition	Brodmann area	Brain region	Cluster volume (mm^3)	Peak x	Peak y	Peak z	Mean t-value
I		R Ant MTG	2,187	34	-70	20	3.9670
I	19, 37	L EBA	1,566	-46	-73	-0	4.6631
I	22	R STG	540	58	-37	20	4.4606
I	20	R MTG	297	52	-46	-6	4.1695
Flame	17, 18	R Lingual g	3,672	-13	-85	-6	-4.5699
Flame	17, 18	L Lingual g	3,483	22	-82	-3	-4.3592
Flame	37	L Fusiform g	324	-37	-61	-15	-4.1808

EBA = extrastriate body area; MTG = middle temporal gyrus; STG = superior temporal gyrus; Ant = anterior. Corrected p = .05 for clusters at least 999 mm^3.

Table 6.
Contrast between individuals: Oprah > Flame

Condition	Brodmann area	Brain region	Cluster volume (mm^3)	Peak x	Peak y	Peak z	Mean t-value
Opr	6	L Precentral gyrus	270	-55	-4	41	4.0849
Flame	34	R Amygdala	540	37	4	-12	-3.9554
Flame		R Caudate Tail	405	19	-28	23	-4.0449
Flame		L Caudate Tail	297	-19	-34	23	-4.1205
Flame		R Caudate Tail	270	25	-40	11	-4.3669

Corrected p = .05 for clusters at least 999 mm^3.

Table 7.

Contrast between properties: Abstract > Concrete

Condition	Brodmann area	Brain region	Cluster volume (mm^3)	Peak x	Peak y	Peak z	Mean t-value
Abstract	40	R Inf Par lob	324	55	-37	26	4.1902
Concrete	37	L Fusiform/ITG/MTG	3,051	-46	-52	-12	-4.5129
Concrete	46	R MFG	2,646	43	34	17	-4.5178
Concrete	40	L Inf Par Lob	2,565	-40	-43	38	-4.6477
Concrete	46	L MFG	2,025	-40	34	14	-4.1921
Concrete	13, 45	L IFG / Insula	1,134	-25	16	2	-4.2579
Concrete	8, 9	L MFG	837	-46	25	35	-4.1675
Concrete	44	L IFG Insula	756	-46	13	11	-4.3366
Concrete	13	L Post Insula	729	-40	-7	-3	-4.7101
Concrete	47	R IFG / MFG	621	22	34	-0	-4.0634
Concrete	40	R Inf Par Lob	621	55	-52	38	-4.5366
Concrete	6, 9	L Precentral gyrus/IFG	540	-40	1	29	-4.4100
Concrete	6	dmPFC	486	-1	31	35	-4.2692
Concrete	34	L Amygdala / EC	432	-28	1	-15	-4.8411
Concrete	34	R Amygdala / EC	432	25	-7	-9	-4.8411
Concrete		R Putamen	297	22	-4	2	-4.2665
Concrete	8, 9	R MFG	297	49	13	35	-4.1472

ITG = inferior temporal gyrus; MTG = middle temporal gyrus; Inf Par Lob = inferior parietal lobule; IFG = inferior frontal gyrus; MFG = middle frontal gyrus; dmPFC = dorsomedial prefrontal cortex; EC = entorhinal cortex; Post = posterior. Corrected p = .05 for clusters at least 999 mm^3.

Table 8.
Contrast: Human properties > Object properties

Condition	Brodmann area	Brain region	Cluster volume (mm^3)	Peak x	Peak y	Peak z	Mean t-value
Human	8, 9, 10	vmPFC / pACC	23,193	-7	46	-3	4.7301
Human	21	L MTG	8,127	-55	-1	-18	4.3546
Human	21	R MTG	6,696	52	-7	-12	4.4684
Human	31	PCC	4,860	1	-46	26	4.8685
Human	47	L OFC	2,889	-28	16	-12	4.8751
Human	6	L dmPFC	2,349	-7	25	56	4.8952
Human	8	R dmPFC	2,187	10	37	53	4.3633
Human	41	R STG	1,917	55	-19	8	4.2322
Human	25	sACC	1,701	-1	7	-6	5.4554
Human	39	R TPJ	1,377	46	-58	17	4.2238
Human	24	Mid Cingulate	1,080	-4	-19	38	4.9075
Human	37	R Parahip. g	810	22	-46	-9	4.5134
Human	39	L TPJ	783	-43	-55	20	4.1452
Human		L MTG / STG	540	-34	-55	8	4.0163
Human	40	R Inf Par Lob	540	55	-28	41	4.1881
Human		R Mid Occ g	513	34	-70	14	4.2582
Human		R Amygdala	405	22	-13	-15	4.1834
Human	22	R MTG	324	52	-37	2	4.1333
Human		R Precentral g	324	52	-10	26	4.1413
Human	45	L IFG	297	-46	25	5	4.1721
Human	3	L Precentral g	270	-52	-16	38	4.4632
Human	6	R MFG	270	7	-25	62	4.0435
Object	37	L Fusiform g	1,323	-43	-43	-12	-4.8149
Object	35, 36	L Parahip g	594	-25	-31	-15	-4.6613

MTG = middle temporal gyrus; STG = superior temporal gyrus; sACC = subgenual anterior cingulate cortex; pACC = pregenual anterior cingulate cortex; PCC = posterior cingulate cortex; OFC = orbitofrontal cortex; Inf Par Lob = inferior parietal lobule; Mid Occ g = middle occipital gyrus; IFG = inferior frontal gyrus; MFG = middle frontal gyrus; vmPFC = ventromedial prefrontal cortex; dmPFC = dorsomedial prefrontal cortex; EC = entorhinal cortex; Post = posterior. Corrected p = .05 for clusters at least 999 mm^3.

Table 9.
Contrast: Individuals > Properties

Brodmann area	Brain region	Cluster volume (mm³)	Peak x	Peak y	Peak z	Mean t-value
		Large Cluster #1				
10	L MFG	72	-25	58	11	4.8164
8	L DLPFC	19	-22	40	38	5.2068
9	L DLPFC	12	-25	40	35	4.6159
	L Caudate	28	-7	7	-0	4.8448
	L Cingulate g	78	-16	1	32	5.0866
	L EBA	16	-31	-67	8	5.5840
8	R DLPFC	48	25	22	47	4.5957
13	L Post Insula	11	-40	-1	0	5.2957
	R Cingulate g	51	19	-4	26	4.5724
31, 24	R Cingulate g	75	4	-25	38	4.4457
		Large Cluster #2				
19	R Middle Occipital g	13	52	-58	-3	5.0113
19	R Cuneus	28	22	-73	32	5.1827
	R Middle Occipital g	11	34	-76	17	4.0485
		Isolated Clusters				
10	R Frontal Pole	9,315	19	61	5	4.7012
39, 40	R Inf Par Lob	6,183	40	-58	38	4.2282
31	R PCC	4,725	4	-25	38	4.4066
8	R MFG	2,997	25	22	47	4.4219
7, 19, 31	R Precuneus/Cuneus	2,565	22	-73	32	4.8631
	Caudate	2,079	28	-28	2	3.1342
4	Paracentral Lobule	1,728	-1	-34	71	4.2748
19, 37	R Mid Occ G	1,377	52	-58	-0	4.6680
4, 43	L Precentral G	675	-61	-4	17	4.0184
40	L Inf Par Lob	648	-61	-37	29	4.1099
21	R MTG	540	64	-22	-3	4.3119
37	L Posterior ITG	351	-52	-67	-0	3.8400
	L Precuneus	351	-22	-73	29	3.9688
40	L Inf Par Lob	351	-49	-49	47	4.1411
34	L Subcallosal G	297	-13	1	-12	4.8758

ITG, MTG, and STG = inferior, middle, and superior temporal gyri; pACC = pregenual anterior cingulate cortex; PCC = posterior cingulate cortex; OFC = orbitofrontal cortex; Inf Par Lob = inferior parietal lobule; Mid Occ g = middle occipital gyrus; IFG = inferior frontal gyrus; MFG = middle frontal gyrus; SFG = superior frontal gyrus; vmPFC = ventromedial prefrontal cortex; Sup Par Lob = superior parietal lobule; NAcc = nucleus accumbens. Two large clusters, labeled as such, were further parsed using anatomical masks as described in Methods section (see Figure 8). Corrected p = .05 for clusters at least 999 mm^3.

Table 10.
Contrast: Properties > Individuals

Brodmann area	Brain region	Cluster volume (mm³)	Peak x	Peak y	Peak z	Mean t-value
		Large Cluster #1				
9	L dmPFC	26	-7	52	35	-5.0973
8	L DLPFC	32	-13	37	50	-6.4196
46	L DLPFC	68	-49	37	2	-6.2400
6	L SFG	22	-10	28	53	-4.6966
47	L OFC	71	-40	25	-6	-5.7289
45	L VLPFC	65	-49	22	20	-5.7964
13	L Ant Insula	31	-28	22	5	-4.6924
32	L Cingulate g	61	-4	16	41	-4.5443
44	L VLPFC	27	-49	13	17	-5.5479
23	L STG	23	-43	13	-27	-4.4423
32	L dmPFC	29	-7	10	47	-4.8843
6	L SFG	252	-7	7	56	-5.0080
9	L DLPFC	58	-55	4	26	-4.9688
	L Putamen	34	-16	4	5	-4.8069
21	L MTG	10	-49	4	-18	-3.9282
	L Uncus	10	-31	-7	-27	-4.2247
3	L Postcentral g	70	-40	-19	50	-6.1871
	L Thalamus	135	-13	-19	8	-6.2301
	L Substantia Nigra	11	-13	-22	-3	-4.9613
4	L Precentral g	59	-31	-28	50	-5.5620
18	L Middle Occipital g	11	-19	-85	-6	-6.1621
47	R OFC	15	34	25	2	-4.7181
32, 24	R Cingulate g	68	10	13	38	-4.4271
6	R SFG	37	4	10	47	-5.5581
32	R dmPFC	25	4	7	47	-4.8759
6	R Precentral g	33	25	-10	50	-5.2244
	R Thalamus	72	13	-16	11	-4.7344
		Large Cluster #2				
37	L Fusiform g	18	-40	-43	-15	-4.2001
	L Culmen	18	-10	-61	-3	-3.9891
	L Declive	16	-37	-61	-15	-4.4406
23, 30	L Cuneus	30	-10	-70	8	-4.4173
19	L Fusiform g	11	-34	-73	-12	-4.7095
	L Declive	16	-16	-76	-12	-4.4245
19	L Lingual g	155	-19	-82	-6	-4.6710
	R Culmen	152	28	-43	-24	-4.7503
30	R Post Cingulate	25	10	-67	11	-4.3010
23, 30	R Cuneus	40	10	-70	8	-4.1656
	R Lingual g	13	13	-70	5	-3.9525

17	R Lingual g	59	22	-88	0	-4.1233
18	R Inf Occipital g	41	34	-88	-6	-4.4838
18	R Mid Occipital g	30	25	-94	11	-5.0157
	R Cuneus	12	25	-94	2	-4.4268
		Isolated Clusters				
8, 9	L Sup Front g	6,804	-13	37	50	-5.3695
13, 45, 47	R OFC/Insula	2,403	34	25	5	-4.6919
6	R MFG	1,917	22	-1	50	-5.3499
7	L Precuneus	1,836	-22	-55	50	-4.5817
37	L Fusiform g	1,215	-43	-43	-15	-4.2868
9	R IFG/MFG	999	55	10	32	-4.2810
22	L MTG	810	-55	-40	2	-4.1304
39	L STG	648	-49	-58	20	-4.1932
7	R Sup Par Lob	540	25	-52	56	-4.2047
6	R Precentral g	378	40	-16	62	-3.9624
13	R Post Insula	351	31	-19	20	-4.1606
11	vmPFC	324	-1	34	-15	-4.0908
45	R IFG	324	46	25	17	-4.3802
18	Cuneus	270	4	-82	17	-3.8149

ITG = inferior temporal gyrus; MTG = middle temporal gyrus; STG = superior temporal gyrus; pACC = pregenual anterior cingulate cortex; PCC = posterior cingulate cortex; OFC = orbitofrontal cortex; Inf Par Lob = inferior parietal lobule; Mid Occ g = middle occipital gyrus; IFG = inferior frontal gyrus; MFG = middle frontal gyrus; SFG = superior frontal gyrus; vmPFC = ventromedial prefrontal cortex; Sup Par Lob = superior parietal lobule; NAcc = nucleus accumbens. Two large clusters, labeled as such, were further parsed using anatomical masks as described in Methods section (see Figure 8). Corrected p = .05 for clusters at least 999 mm^3.

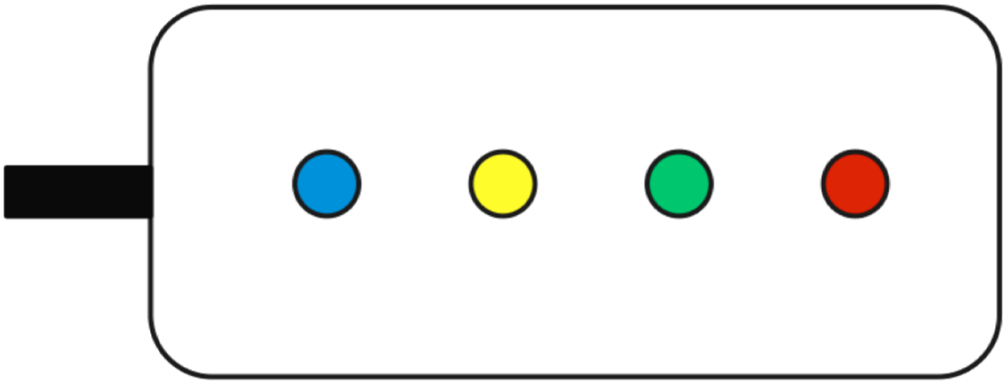


Figure 1. Schematic drawing of fMRI button box used by participants

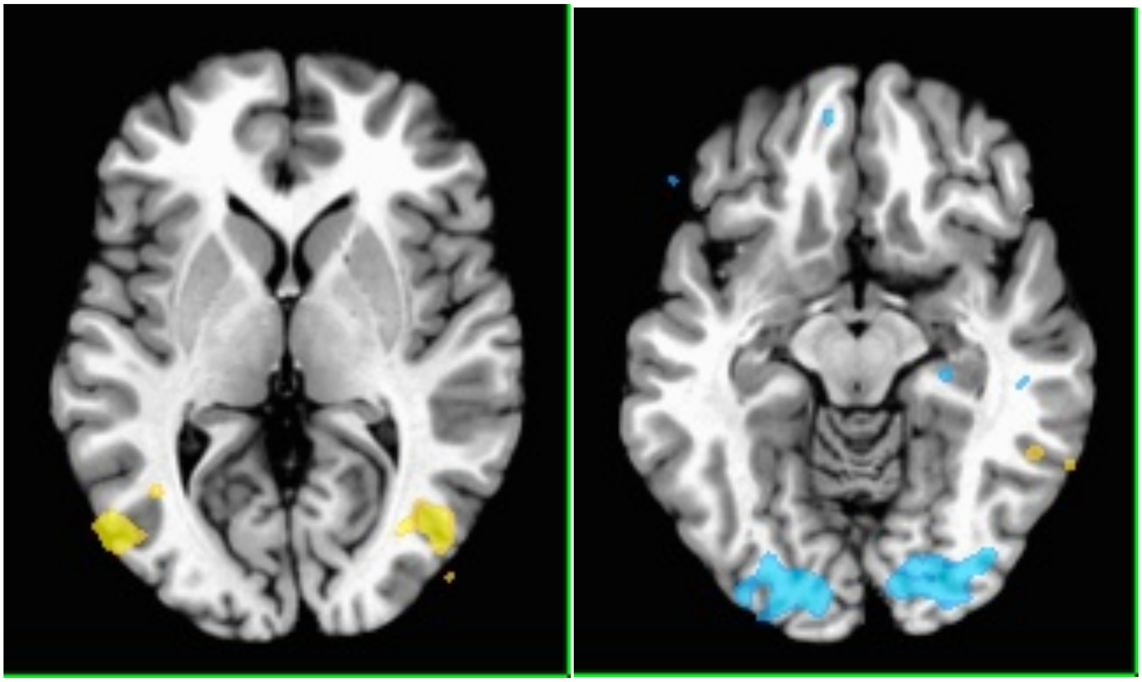


Figure 2. Extrastriate body area active for "I" (left) and lingual gyrus active for "Oprah" and "Flame" (right)

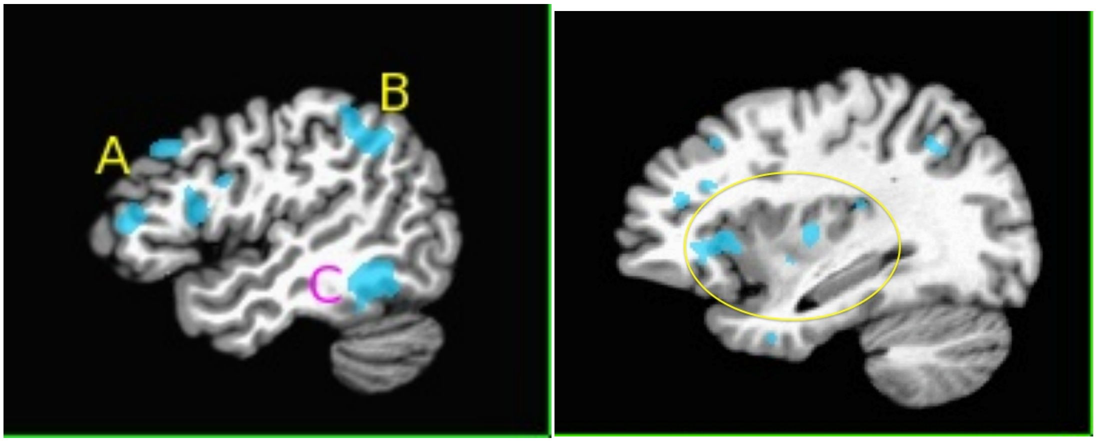


Figure 3. Activations for concrete properties. Left: left frontoparietal network including inferior and middle frontal gyri (A) and inferior parietal lobule (B); Left fusiform gyrus (C). Right: left insula (circled)

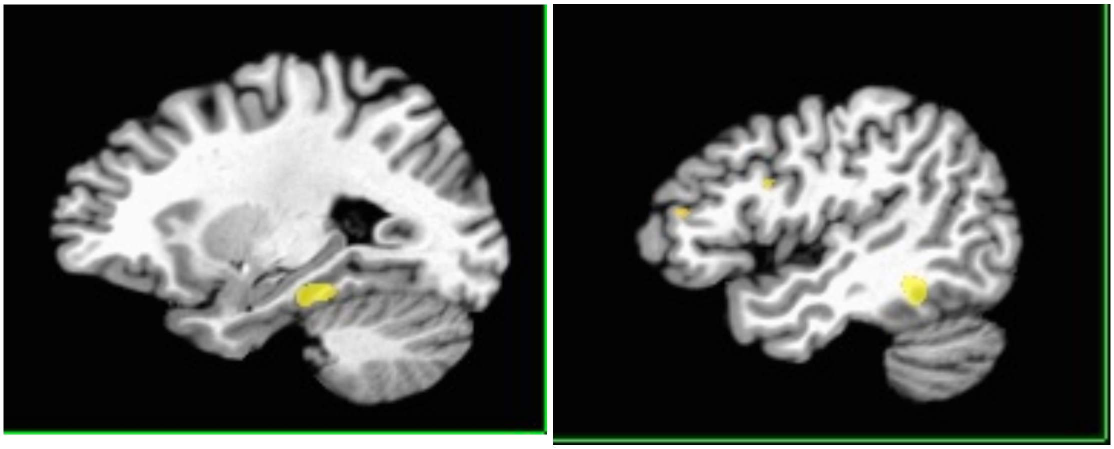


Figure 4. Activations for “Flame” in the left parahippocampal gyrus (left) and left fusiform gyrus (right)

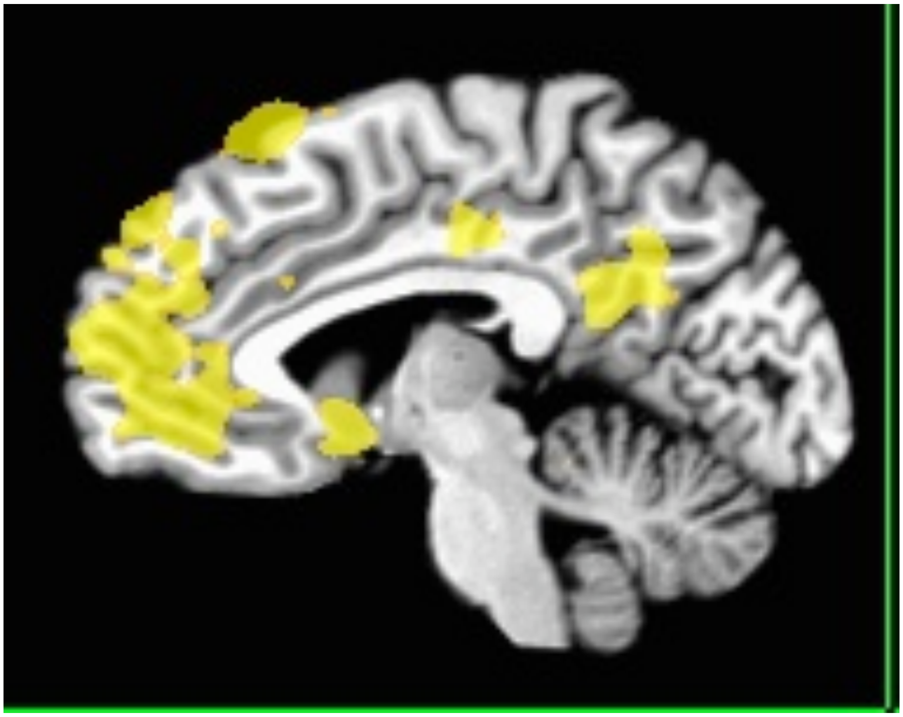


Figure 5. Activations for properties relevant to humans (“I” and “Oprah”). Left: cortical midline structures including ventromedial and dorsomedial prefrontal cortices and posterior cingulate cortex.

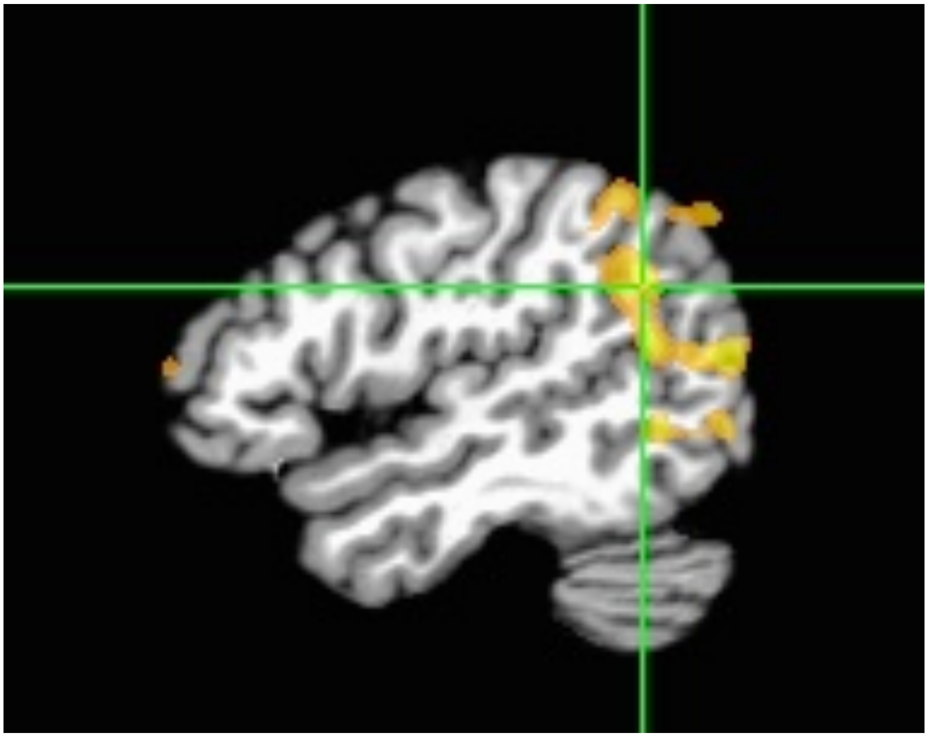


Figure 6. Activation for individuals in right temporoparietal junction (crosshairs)

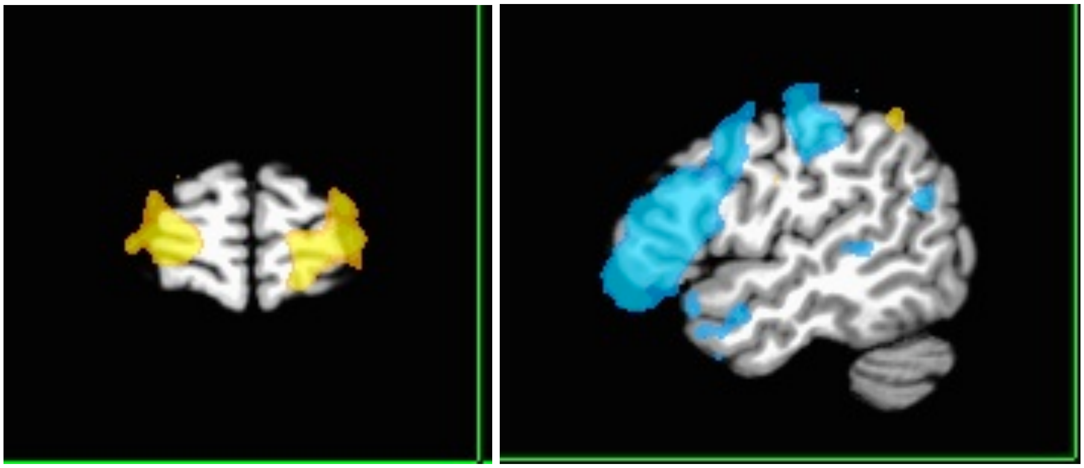


Figure 7. Activation for individuals in frontal poles (left) and for properties in left dorsomedial prefrontal cortex (right)

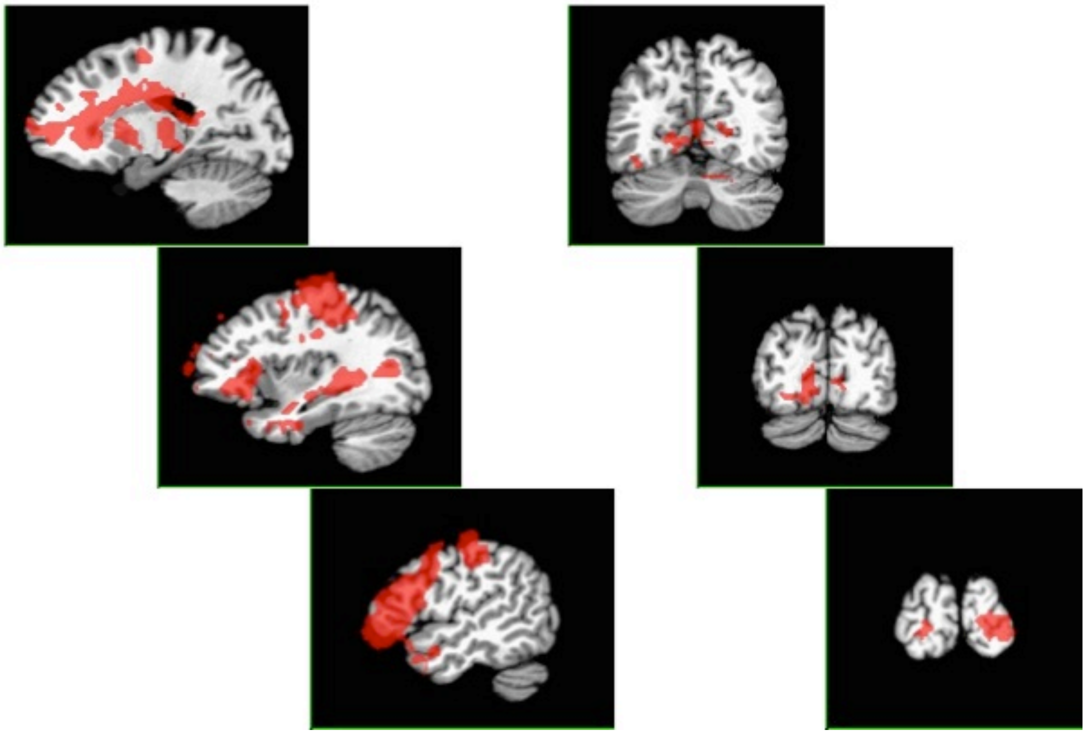


Figure 8. Large clusters in the Individuals > Properties contrast that were broken down using anatomical masks. Left: the larger of the two clusters. Right: the smaller of the two clusters. Note that these clusters contained voxels significantly active for both conditions, meaning that t-values could be either significantly positive or negative. The masking technique described in the methods section broke down these large clusters according to anatomical region and according to the sign of the t-test.

Appendix 1 – Oprah Description

Oprah Winfrey is a classic example of an American success story. Growing up amidst considerable hardship in rural Mississippi and later in inner city Milwaukee, Oprah would become one of the most successful people in the world. Among other things, she is an award-winning talk show host, an entrepreneur, and a philanthropist.

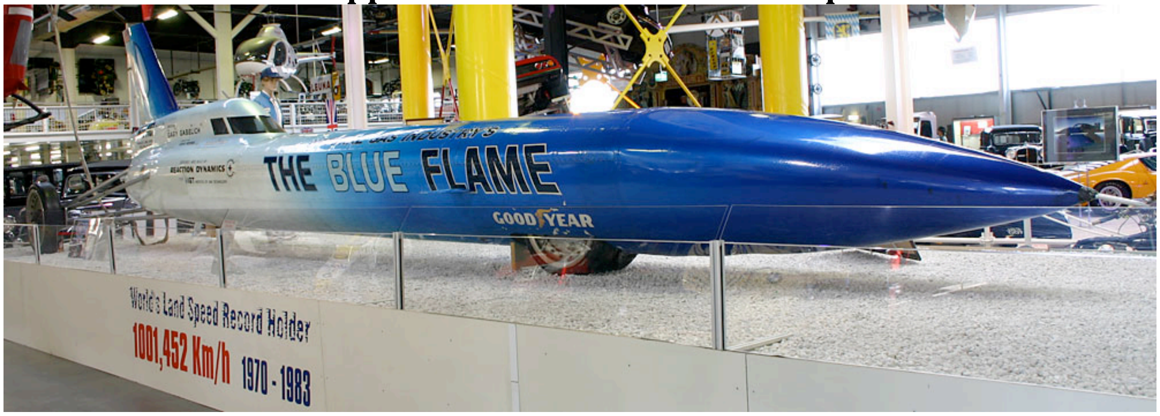
Out of an often-difficult childhood, Oprah emerged as an exemplary student. She skipped two grades in elementary school, earning a scholarship to Nicolet High School in Glendale, Wisconsin. Due to conflict at home, however, she went to live with her father in Tennessee a year later. She eventually attended Tennessee State University on a full scholarship.

Oprah as a media personality got her start as a co-anchor for the local evening news when she was only 19. Ten years later, she took over as host for a daytime talk show called *AM Chicago*. The program was renamed *The Oprah Winfrey Show*, and Oprah's straightforward and intimate interviews were soon broadcast to a national audience. Since then, *The Oprah Winfrey Show* has become the highest-rated talk show in the history of American television. It has been on the air for more than 23 years, and is still wildly popular.

Besides being known for her uplifting attitude and positive message of empowerment and generosity on television screens nationwide, Oprah has come to be known for her philanthropic efforts on the world stage. The Oprah Winfrey Leadership Academy for Girls provides educational opportunities for underprivileged and academically gifted girls in South Africa. Oprah founded the school with $40 million of her own money, and was actively involved in designing the buildings, selecting the students, and hiring the faculty. Oprah thinks of the girls in her school as her daughters, and considers their safety and success a personal mission.

Through The Angel Network, an organization she founded in 2000, Oprah's philanthropic efforts today are aimed at protecting human dignity and human rights, through such avenues as helping the poor, the homeless, and abused children, particularly in developing countries.

Appendix 2 – Blue Flame Description



The Blue Flame is the now world-famous car that broke the world land-speed record in 1970. The record set by the Blue Flame – just over 630 miles per hour – was untouched until thirteen years later. The success of the rocket-powered car in setting a new record for speed was a result of a coordinated effort between several industrial organizations and engineering groups. Their dream was realized through the cooperation of hi-tech science and American entrepreneurial determination.

The incredible feat took place on the Bonneville Salt Flats in Utah, a site that is well known in the automotive world for the large number of records that have been broken there. The area has a rich history, including the construction of a railway line almost a hundred years ago. It was first used as a racing venue just before the onset of World War I, when a 1914 run unofficially broke the world land-speed record. The Bonneville Salt flats are ideal because they are what the name implies: flat. This has allowed phenomenal cars such as the Blue Flame to attain unparalleled velocities without having to deal with obstacles, inclines, or bumps in the road.

The Blue Flame's record setting run was actually a series of two runs, in the same direction, carried out on consecutive days. In the past, an official world record required two runs in opposite directions. However, a disastrous crash at Bonneville Speed Week prompted a revision of the rules. To the present day, records are set and broken according to the same standards that the Blue Flame overcame almost forty years ago.

The Blue Flame now is on display at the Auto & Technik Museum in Sinsheim, Germany. The museum welcomes over 1 million visitors every year, many of whom come to see the famous Blue Flame, housed among the vintage cars, motorcycles, and steam engines of the Auto & Technik Museum.