How the Human Brain Goes Virtual: Distinct Cortical Regions of the Person-Processing Network Are Involved in Self-Identification with Virtual Agents

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Millions of people worldwide engage in online role-playing with their avatar, a virtual agent that represents the self. Previous behavioral studies have indicated that many gamers identify more strongly with their avatar than with their biological self. Through their avatar, gamers develop social networks and learn new social-cognitive skills. The cognitive neurosciences have yet to identify the neural processes that underlie self-identification with these virtual agents. We applied functional neuroimaging to 22 long-term online gamers and 21 nongaming controls, while they rated personality traits of self, avatar, and familiar others. Strikingly, neuroimaging data revealed greater avatar-referential cortical activity in the left inferior parietal lobe, a region associated with self-identification from a third-person perspective. The magnitude of this brain activity correlated positively with the propensity to incorporate external body enhancements into one's bodily identity. Avatar-referencing furthermore recruited greater activity in the rostral anterior cingulate gyrus, suggesting relatively greater emotional self-involvement with one's avatar. Post-scanning behavioral data revealed superior recognition memory for avatar relative to others. Interestingly, memory for avatar positively covaried with play duration. These findings significantly advance our knowledge about the brain's plasticity to self-identify with virtual agents and the human cognitive-affective potential to live and learn in virtual worlds.

Keywords: fMRI, memory, new media, self-identification, virtual agents

Introduction

Recent sociotechnical developments involving online virtual worlds have made possible new ways in which human beings can experience the self (Yee 2006; Ash et al. 2007; Bainbridge 2007; Donath 2007; Gorini et al. 2007). Today, millions of people across the globe inhabit online virtual worlds, where they engage in work, play, and adventures via an online artificial agent or avatar (Yee 2006; Bainbridge 2007). Through their avatar, an online animated character that represents the self, gamers establish friendships, develop new social skills, and express their individuality (Yee 2006; Miller 2007). Long-term gamers gradually build an avatar-centered autobiographical narrative of their online adventures and social relations.

Interestingly, role-playing games with avatars are increasingly used in training programs for highly specialized personnel, such as astronauts and people in the military (Rauterberg et al. 2008; Wilson 2008). Moreover, gamers are progressively encouraged to add valuable gaming experiences, such as leadership qualities and people skills, to their professional resume (Miller 2007; Faylor 2008).

In future human societies, the personal identity of many individuals may by default include an avatar that parallels our biological self in complexity and experiential richness. Entire generations may grow up living, learning, and socializing in online virtual environments. Today, a glimpse of such a futuristic human life is provided by players of massively multiplayer online role-playing games, such as Second Life and World of Warcraft (WoW; for a detailed explanation, see Bainbridge, 2007). Role-playing through their avatar, these gamers roam the virtual worlds for more than 20 h per week (Yee 2006).

Evidence from sociology and cyberpsychology indicates that long-term players of online role-playing games incorporate the avatar into their self-concept (Turkle 1994, 1995; Miller 2007). Some gamers seem to identify even more strongly with their avatar than with their real self (Bessière et al. 2007; Yee et al. 2009). Sense of agency and control over the avatar (Pearce and Artemesia 2006) as well as the intense emotional involvement (Ravaja et al. 2006; Bessière et al. 2007) of gamers during online role-playing may facilitate this kind of self-identification. Yet despite growing research on the neural basis of self-representation (Gillihan and Farah 2005; Legrand and Ruby 2009; Christoff et al. 2011), neuroscience has yet to address how humans self-identify with these online artificial agents.

Using functional neuroimaging of long-term gamers, we addressed this issue by investigating the cognitive neural processes mediating avatar-referencing compared with self-referencing and other-referencing. More specifically, we focused our investigation on 3 key features of self-identification with avatars in massively online role-playing games, namely 1) the third-person visual perspective on the avatar. 2) players' emotional involvement with their avatar, and 3) avatar-related memory.

A unique feature of online role-playing games is that players can control their avatar from an elevated third-person visual perspective (Laird and van Lent 2001). In the third-person gaming mode, players continuously have a visual percept of their avatar while they control its movements in the online world. This third-person perspective (3PP) on the avatar may resemble the 3PP on self, where one imagines oneself as seen from the outside. This 3PP on self can occur during autobiographical memory retrieval and self-projection to the future (Buckner and Carroll 2007). The 3PP on the avatar may also resemble illusory own-body perceptions, such as out-of-body experiences (OBEs; Blanke et al. 2002, 2005; Ehrsson 2007; Lenggenhager et al. 2007). It is also the perspective through which we can imagine how we appear to others, a cognitive ability known as perspective switching and considered to be a basic property of social cognition (Decety and Lamm 2006, 2007).

Whereas the 3PP on the self must be mentally simulated in memory, prospection, and social cognition, the 3PP on the avatar is a visual percept for gamers who play in the third-person

mode. In this respect, self-identification with the perceived avatar may resemble self-identification with the externally perceived own body in OBEs. Thus, gaming may offer a distinct nonpathological form of self-experience in which long-term gamers self-identify with their avatar from a 3PP.

Findings from studies using transcranial magnetic stimulation and direct electrical cortical stimulation provide evidence for a causal relation between disruption of activity in the right inferior parietal lobe, or angular gyrus, and a 3PP on the self (Blanke et al. 2002, 2005). When a 3PP on the self coincides with a disturbed sense of spatial unity between self and body, then an OBE may occur (Blanke et al. 2002, 2005; Ehrsson 2007; Lenggenhager et al. 2007). Some researchers propose that the spontaneous occurrence of OBEs relies on the same functional mechanisms that we use during voluntary mental 3PP-imagery of our own body (Brugger 2002; Blanke et al. 2005).

This implied relation between disruption of the right angular gyrus and 3PP self-identification, however, may not be so clear-cut. Recent theories rather assign a special role to the left hemisphere in self-recognition and self-identification (for a review, see Gazzaniga 2008) as well as sense of agency (for a review, see Decety and Grezes 2006; see also Decety et al. 1997; Ruby and Decety 2001). In describing recent findings on face recognition in split-brain patients, Gazzaniga (2008) hypotheses the role of the right hemisphere in rejecting that a person is self ("Nope, it's not me!") while attributing a key role to the left hemisphere in retrieval of confirmative self-knowledge and self-recognition ("Yep, it's me!"). Does this lateralization also hold for the inferior parietal cortex?

Despite an abundance of literature associating increased activity in the right angular gyrus with detection that the agent of an action perceived from a 3PP is not self but other (Ruby and Decety 2001; Farrer and Frith 2002; Farrer et al. 2004, 2008), evidence for the role of the right hemisphere in confirmative self-identification ("Yep it's me!") remains inconclusive (Gazzaniga 2008).

Meanwhile, empirical evidence is gradually emerging that particularly the left rather than the right angular gyrus may be involved in confirmative self-identification and sense of agency (for a review, see Decety and Grezes 2006). For example, Ruby and Decety (2001) demonstrated that when participants imagined themselves being the agent of an action relative to imagining someone else being the agent, activity in the left angular gyrus increased. The reversed contrast resulted in greater activity in the right angular gyrus.

Another study showed that impairment of the left parietal cortex compromised the correct attribution of agency to self or others (Sirigu et al. 1999). Left parietal patients were more inclined than healthy controls to claim agency of 3PP-observed correct hand movements that were executed by others, even if the patients themselves actually executed the required hand movements incorrectly. In the light of Gazzaniga's hypothesis, this impaired self-other distinction with left parietal lesion patients might be due to aberrant processes of confirmatory self-identification ("Yep it's me!").

Furthermore and as described above, the various studies by Blanke et al. show that reduced activity in the right angular gyrus does not result in confirmatory self-identification, for example, by increased sense of agency ("Yep it's me!") but actually leads to OBEs (Blanke et al. 2002, 2005; Ehrsson 2007; Lenggenhager et al. 2007). OBEs are typically associated with a sense of spatial alienation from one's own physical body, or

disembodiment, whereby the sense of self and sense of agency transfer away from the physical own body and become located in a second, illusory body located at an elevated visuospatial level (Fig. 1A).

In contrast, 3PP-gamers assume full control over their avatar body (Pearce and Artemesia 2006) and may appropriate this avatar body into their own self-concept (Fig. 1B). So despite the superficial similarities between the 2 conditions, in our view, OBEs and the gamer–avatar dyad are 2 distinct phenomena (Fig. 1). In the case of OBEs, there is a confused sense of self and agency that is associated with the illusion of being outside of and alienated from one's own body. In the case of 3PP-gaming, there is an appropriation of the avatar body into the self-concept that logically follows from being in control over the 3PP avatar body.

Based on the phenomenal difference between OBEs and 3PP-gaming, the role of the inferior parietal cortex in agency and the 3PP representation of movement (Grezes and Costes 1998; Farrer and Frith 2002) as well as the hypothesized role of the left hemisphere in confirmative self-identification (Gazzaniga 2008), we hypothesized that left inferior parietal regions play a key role in avatar-referencing and thus more generally in self-identification with the avatar via a 3PP.

It is well known that individuals differ in levels of body plasticity, that is, how easily they incorporate and self-identify with body enhancements (e.g., prosthetics) and external items (e.g., body adornments and accessories; MacLachlan et al. 2003). Hence, not all long-term gamers might identify with their avatar to the same degree. In line with this idea, we predicted that degree of avatar-related activation in the inferior parietal lobe, reflecting self-identification from a 3PP, would correlate positively with individual dispositions to self-identify with external bodies and objects.

A second feature of self-identification with one's avatar, as suggested by research from cyberpsychology (Ravaja et al.
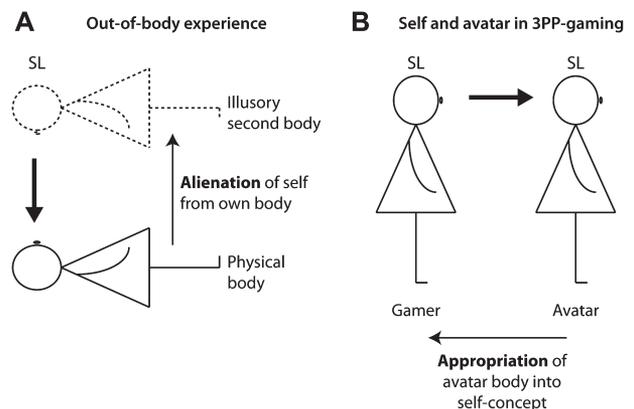

Figure 1. Conceptualization of the phenomenal difference between OBEs and the gamer–avatar experience in 3PP-gaming. (A) During OBEs, the self is alienated from the physical body. Sense of self and agency are located in a second, illusory body. From this elevated visuospatial perspective in the illusory body, the physical body is observed. OBEs often occur in supine position (Blanke et al. 2005; Blanke and Metzinger 2009). (B) In 3PP-gaming, the gamer, typically seated behind a computer screen, sees the avatar from an elevated visuospatial perspective, usually from the back. In contrast to OBEs, gamers assume full control over their avatar body. This gaming experience may facilitate appropriation of the avatar body into the gamers' self-concept. Due to presence during gaming, self-location may transfer to the avatar body, alternate back and forth between the gamer's body and the avatar body, or may be present in both gamer and avatar (bilocation). Bold arrows indicate egocentric viewing direction. SL = self-location. Modified after Blanke and Metzinger (2009).

2006; Bessière et al. 2007), is gamers' intense emotional involvement with their avatar. Earlier neuroimaging studies have shown that the rostral part of the anterior cingulate gyrus (rACG), which borders the medial prefrontal cortex, plays an important role in the evaluative representation of both emotions (Bush et al. 2000; Gusnard et al. 2001) and bodily sensations (Leknes and Tracey 2008). Based on experimental evidence that rACG activity differentiates self from others (Damasio 1999; Bush et al. 2000; Gusnard et al. 2001; David et al. 2006; Heatherton et al. 2006; Schilbach et al. 2006; Leknes and Tracey 2008), we hypothesized that emotional self-involvement with the avatar should be reflected by greater avatar-related rACG activity relative to familiar others.

A third feature of self-identification with one's avatar, as indicated by research from cyberpsychology (Turkle 1994, 1995; Pearce and Artemesia 2006; Miller 2007), is the "virtual autobiography," or avatar-centered narrative, that long-term gamers build by role-playing through their avatar. How does this avatar-centered narrative relate to one's autobiographical narrative, the narrative one builds in interaction with close others or the narrative one develops by observing familiar distant others? Interestingly, a substantial body of memory research demonstrates that memory for self-related information, also called self-referent information, is superior to memory about others, or other-referent information (for meta-analyses, see Symons and Johnson 1997; Mashek et al. 2003). However, this memory advantage for self-referent information relative to other-referent information decreases if the other person is a close other. Other-referent memory is thus enhanced by interpersonal closeness (Symons and Johnson 1997; Mashek et al. 2003).

It remains a topic of investigation, however, to what extent self-identification by role-playing through an avatar modulates avatar-referent memory. In the case of avatars, one cannot really speak of interaction or interpersonal closeness with one's avatar, as the avatar is a form of self-representation. Gamers act through the avatar and do not interact with the avatar. Self-identification with the avatar may foster avatar-referent memory strategies that mimic the advantageous self-referent memory strategies.

Considering results from previous studies indicating that many gamers strongly self-identify with their avatar (Turkle 1994, 1995; Yee 2006; Bessière et al. 2007; Yee et al. 2009), we hypothesized that avatar-referent memory would be superior to memory for familiar others. Moreover, we predicted that duration of the role-playing experience with the avatar would enrich the avatar-centered narrative and hence facilitate avatar-referent memory, as a feature of self-identification with one's avatar.

To test these hypotheses, we scanned 22 healthy long-term players of WoW (Blizzard Entertainment Inc., Irvine, CA) (Bainbridge 2007; Yee et al. 2009). We selected long-term gamers who played only in third-person mode. Participants rated the applicability of personality trait words (e.g., nasty, courageous) to their avatar, self, close other, and familiar distant other in a so-called implicit encoding–recognition memory paradigm (Rogers et al. 1977; Symons and Johnson 1997; Mashek et al. 2003; Heatherton et al. 2006; Vanderwal et al. 2008). The idea behind the implicit encoding–recognition paradigm is that while participants rate the applicability of traits (e.g., nasty, courageous) to the different person conditions (e.g., self, avatar), they implicitly associate the trait word

under consideration with the person condition. We can test the strength of this implicit encoding of trait-person associations by presenting participants with a surprise recognition task after the encoding task (see Materials and Methods). According to previous research (Symons and Johnson 1997; Mashek et al. 2003), the closer the other person is to self, the better the recognition memory for items that were presented with the name of this other person in the preceding encoding task.

To rule out the possibility that gamers exhibit abnormalities in person processing, we compared them with a matched nongaming control group ($n = 21$). Furthermore, to rule out the alternative explanation that avatar-referential activity reflects a mere familiarity effect (i.e., that gamers merely consider their avatar as a familiar animated character), we included a reference condition to a highly familiar animated character, that is, the participants' favorite cartoon character. We further purified all referencing conditions by subtracting neural activation from a low-level control condition, that is, counting syllables (Fig. 2; see Materials and Methods).

Materials and Methods

Participants

Twenty-two right-handed native-Dutch speaking players of WoW (mean age 22.77 years, SD 2.71; 12 males; mean WoW play duration 2.67 years, SD 1.47; mean play frequency 17.82 h per week, SD 8.64) with graduate or undergraduate education levels, normal or corrected-to-normal visual acuity, and without self-reported neurological or psychiatric disorders participated in the experiment. For an explanation of WoW, see Yee et al. (2009). All gamers played only from a third-person (elevated) visual perspective on their avatar.

Additionally, 21 matched nongaming controls (mean age 21.71 years, SD 2.88; 10 males) participated in the study. We asked participants in the control group to indicate their favorite cartoon character, which would serve as their familiar animated character condition (see Supplementary Material). The mean duration the controls considered the cartoon character their favorite was 7.70 years, with a SD of 4.22.

The groups were matched on sex, age, education, and body plasticity. We used the TABP (MacLachlan et al. 2003) to measure the level of body plasticity (see Supplementary Material). Moreover, considering the popular idea that people who are heavily involved in game-playing
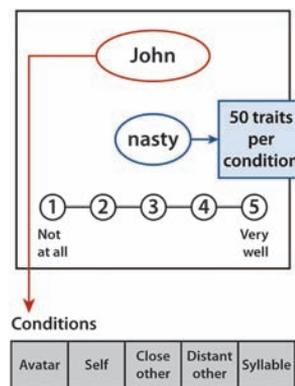

Figure 2. Schematic example of a trait trial as presented to gamers of the online role-playing game WoW (for an explanation of the game, see Bessière et al. 2007; Yee et al. 2009) in the fMRI experiment. Within a response window of 3 s, participants rated the extent to which positive and negative trait words described their avatar, self, close other, and familiar distant other (1 = not at all, 5 = very well). Control conditions included a counting syllables task and a matched nongaming control group, which rated the applicability of trait adjectives to favorite cartoon character instead of avatar (not illustrated; see Materials and Methods).

may have characteristics, such as intense preoccupation, that are related to Asperger's syndrome (Bland 2008; Charlton and Danforth 2009), we also matched both groups on autistic traits. To assess subjects' position on or near the autism spectrum, we used the Autism-spectrum Quotient (AQ, Baron-Cohen et al. 2001, see also SM). All subjects gave written informed consent for this study according to the institutional guidelines set forth by the local ethics committee (Commissie Mensgebonden Onderzoek, region Arnhem-Nijmegen), prior to the experiment. Subjects either received 25 euros or study credits for their participation. Two players and one control participant were excluded from the fMRI data analysis due to technical issues or excessive head motions.

Procedure

Questionnaires

Prior to scanning, all 43 participants completed questionnaires assessing demographics, handedness, psychological and physical health, body plasticity, autism, and the names of their best friend and familiar animated character. For players, the familiar animated character corresponded to their main avatar in WoW, and for controls, the familiar animated character was their favorite cartoon character. Participants also indicated, in years and months, play duration with their avatar (players), how long they had considered the cartoon as their favorite (controls) and how long they had considered their designated close other as their best friend.

Encoding Task: Referential Processing

Referential processing paradigms are widely used in social psychology to assess differences between cognitive processing of self-related and other-related information. (Rogers et al. 1977). These paradigms have recently been adapted to neuroimaging experiments (Damasio et al. 2000; Gusnard et al. 2001; Macrae et al. 2004; Ochsner et al. 2004; Phan et al. 2004; Heatherton et al. 2006) to investigate cognitive neural differences between processing of self and others. In our study, we employed a mixed blocked event-related fMRI design for the referential processing task. The referential processing task also served as the implicit encoding task for the subsequent post-scanning recognition memory task (see below). Participant rated the extent to which traits described avatar, self, close other, and familiar distant other, using a 5-point Likert scale (1 = not at all, 5 = very well [Fig. 2]). We controlled for perceptual and motor effects by including the control condition of counting syllables (range: 1–5 [Supplementary Material]). Furthermore, matched nongaming controls did not have an avatar condition but rated the applicability of traits describing a familiar animated character whose actions they did not control, that is, their favorite cartoon character (Supplementary Material).

While lying in the scanner, participants completed a fixed set of practice trials to become familiar with the custom-made 5-button mouse and the task. The ensuing single fMRI scanning session lasted approximately 44 min (M = 43.80 min, SD = 0.22 min), during which we presented 10 "super blocks," each consisting of 5 trait judgment blocks (e.g., self, avatar, close other, distant other, and syllables) and 5 "baseline" blocks. Each trait judgment block consisted of 5 trait trials related to one person condition only. Trait judgment blocks were alternated by a baseline block, comprising 5 baseline trials, which each consisted of a low contrast gray fixation cross. We included these baseline blocks to allow participants to return to a psychological baseline state where they did not actively think about the person in the previous condition. The order of the blocks was randomized according to two 5 × 5 balanced Latin squares, to ensure that each judgment condition followed immediately after every other judgment condition an equal number of times (Edwards 1962).

Each trait judgment block began with a prompt screen, indicating the name of the person to judge (self, avatar, close other, and familiar distant other). The prompt screen preceding syllable blocks indicated that the next block involved counting syllables. In case of baseline blocks, low-contrast text on the prompt screen informed participants that the ensuing block would be a relax block in which they only needed to keep their eyes focused on the fixation cross. Stimulus presentation lasted 3 s, during which a trait adjective appeared on the center of the screen, the cue appeared above the trait and the 5-point Likert scale occurred below the trait (Fig. 2). Trait trials, baseline trials, and prompt screens were pulse locked and had a fixed duration of 4400 ms or 2 time repetition [TR]. The interstimulus interval (time interval between stimulus offset and subsequent stimulus onset) within a block varied between 400 and 2400 ms, with an average of 1400 ms. Text screens were presented in off-white Arial font and centered on a black background.

Post-Scanning Surprise Recognition Task

After the scanning session, participants completed a filler task for 5 min while seated behind a standard computer in a test cubicle, followed by a self-paced surprise recognition task, which lasted approximately 12 min (M = 11.57 min, SD = 3.15). Participants viewed the 250 trait adjectives previously presented during the referential processing task randomized along with 250 novel trait adjectives that had not been presented during scanning. Words appeared individually in the center of the computer screen and were followed by the next word immediately after the participant had responded. Using left- and right-handed key presses, participants indicated for each word whether they had seen the word in the scanner or not. The order of response buttons for Yes and No was counterbalanced across subjects, so that half of the players and controls had to respond with Yes by pressing the right key. We calculated performance in the recognition memory test, that is, d-prime, as the difference between z-transforms of hit rate and false alarm rate (Macmillan and Creelman 2005/1991).

Apparatus

All neuroimaging took place at the Donders Centre for Cognitive Neuroimaging (DCCN, Donders Institute for Brain, Cognition and Behaviour, Radboud University Nijmegen, Nijmegen, the Netherlands) using a Siemens Trio 3T whole-body MR scanner (Erlangen, Germany) with a standard birdcage head coil. An LCD projector presented the stimuli onto a rear projection screen mounted at the head end of the scanner bore. Participants viewed the stimuli through a custom made mirror positioned on the head coil. All stimuli were delivered using Presentation software version 12.2 (Neurobehavioral Systems, Davis, CA) run on a Dell Workstation (Austin, TX).

fMRI Data Acquisition

We collected all functional images in a single scanning session using an echo-planar imaging sequence sensitive to blood oxygen level–dependent contrast (T_2^*) (TR = 2200 ms, time echo [TE] = 35 ms, flip angle = 90°, voxel size = 3.5 × 3.5 × 3.0 mm). The 1210 volumes (34 transversal slices, slice gap = 0.5 mm, field of view = 224 mm, slice matrix size = 64 × 64) were acquired in ascending order and allowed for complete brain coverage, except parts of the cerebellum. Following functional imaging, we acquired anatomical images using a T_1-weighted 3D magnetization prepared rapid gradient echo sequence (192 sagittal slices, TR = 2300 ms, TE = 3.03 ms, flip angle = 8°, voxel size = 1 × 1 × 1 mm).

fMRI Data Analysis

We preprocessed and analyzed functional imaging data in SPM5 (Wellcome Institute of Cognitive Neurology, London, UK; http://www.fil.ion.ucl.ac.uk/spm), using a general linear model. Preprocessing steps involved spike removal, spatial realignment, slice timing correction, extended coregistration, normalization to the Montreal Neurological Institute (MNI) template with a resolution of 2 × 2 × 2 mm, and spatial smoothing by an isotropic 8-mm full-width at half-maximum Gaussian kernel. For each participant, we computed linear contrasts of parameter estimates (β) for each comparison at each voxel. These contrast images were subsequently entered into random-effects analyses. In these random-effects analysis, resulting SPMs of the t-statistic were corrected for multiple comparisons at the cluster level, using a voxel-wise threshold of $P < 0.001$. Moreover, in line with previous research demonstrating brain areas preferentially related to self-referential processing (Damasio et al. 2000; Gusnard et al. 2001; Macrae et al. 2004; Ochsner et al. 2004; Phan et al. 2004; Heatherton et al. 2006), we defined a region of interest (ROI) in the rostral anterior cingulate gyrus (rACG), bordering with the medial prefrontal cortex. We first localized the self-referencing region by testing the contrast Self > (Avatar, Close Other, and Familiar Distant Other) in the players group ($n = 20$), which yielded a cluster in the right rACG with a peak voxel at MNI coordinates 2, 38, 12. We then used MarsBaR v0.42 software (http://marsbar.source forge.net) to import an image of the significant SPM cluster to create the ROI and to perform subsequent independent ROI analyses. The independent post hoc comparisons consisted of Avatar > Close Other and Avatar > Familiar Distant Others as well as the independent control comparison (Avatar > Syllable)$_{PLAYERS}$ > (Cartoon > Syllable)$_{CONTROLS}$. The post hoc comparisons explicitly did not include the Self condition, which was used to create the ROI, so our analyses are not susceptible to the so-called "double-dipping" (Kriegeskorte et al. 2009).

We conducted the fMRI analyses in 4 steps. In the first step, we sought to replicate findings from previous literature (Damasio et al. 2000; Gusnard et al. 2001; Macrae et al. 2004; Ochsner et al. 2004; Phan et al. 2004; Heatherton et al. 2006) indicating the involvement of the medial prefrontal, inferior parietal, and temporal cortices in general person processing, by testing the contrast All Biological Persons > Syllable in a whole-brain analysis, across all subjects. The label "All Biological Persons" corresponds to the conditions Self, Close Other, and Familiar Distant Other.

In the second step, we empirically tested 2 a priori assumptions, namely 1) that players do not differ from controls in the way they engage in person processing, by conducting a two-sample t-test of the contrast All Biological Persons > Syllable and 2) that processing of familiar animated characters is similar to processing of biological persons. To this end, we performed a conjunction analysis of (Avatar > Syllable) Λ (All Biological Persons > Syllable) in the players group to assess which brain regions become commonly activated for both avatar AND biological persons, relative to counting syllables. Similarly, in the control group, we performed a conjunction analysis of (Cartoon > Syllable) Λ (All Biological Persons > Syllable). We performed both conjunction tests on a whole-brain analysis by testing against the conjunction null hypothesis that there is no effect of condition A (e.g., Avatar > Syllable) OR B (e.g., All Biological Persons > Syllable) (Nichols et al. 2005).

The third step in the fMRI analysis centered around the whole-brain analyses of the key comparisons Avatar > Self and Avatar > Biological Others (close other, familiar distant other). In addition to these comparisons, we compared avatar-referencing in players with cartoon-referencing in controls to confirm that the predicted greater inferior lobe activation for avatar was indeed related to avatar-referencing and could not be explained by a mere familiarity effect of familiar animated characters in general. Control comparisons were: Cartoon > Self and Cartoon > Biological Others in the control group. In these 2 contrasts, we expected to find no significance. As a final confirmation, we conducted the two-sample t-test of (Avatar > Self)$_{PLAYERS}$ > (Cartoon > Self)$_{CONTROLS}$.

The fourth and final step in the fMRI analysis concerned the hypothesis that avatar-referencing involves greater emotional self-involvement than other-referencing, such as close and familiar distant others. To test this hypothesis, we performed the 3 independent post hoc ROI analyses described above, using the rACG as ROI. We tested the comparisons Avatar > Close Other and Avatar > Familiar Distant Other in the players group. Additionally, we conducted the control two-sample t-test (Avatar > Syllable)$_{PLAYERS}$ > (Cartoon > Syllable)$_{CONTROLS}$. In these 3 contrasts, we expected to find greater avatar-referential rACG activity, as an indication of greater emotional self-involvement of players with their avatar.

Results

To investigate our main hypothesis that avatar-referencing compared with self- and other-referencing would rely mostly on a 3PP and thus generate more activity in the angular gyrus, we compared avatar-referencing to self-referencing and other-referencing in 2 whole-brain analyses. Strikingly, results revealed greater activity for avatar in the left angular gyrus of the inferior parietal lobe (Fig. 3A), relative to self (Brodmann area [BA 39]), $t_{95} = 4.83$, $P = 0.001$ corrected, and relative to close other and distant other, $t_{95} = 4.66$, $P = 0.015$ corrected. Additional control comparisons ruled out a mere familiarity effect (see supporting online text in Supplementary Material and Supplementary Table S3).

Notably, and as predicted, the magnitude of this avatar-referential activity in the left angular gyrus correlated positively with gamers' level of body plasticity, $r = 0.46$, $P = 0.042$ two-tailed, $n = 20$ (Fig. 3B), as measured with the Trinity Assessment of Body Plasticity (TABP; MacLachlan et al. 2003). This well established clinical questionnaire indicates the ease
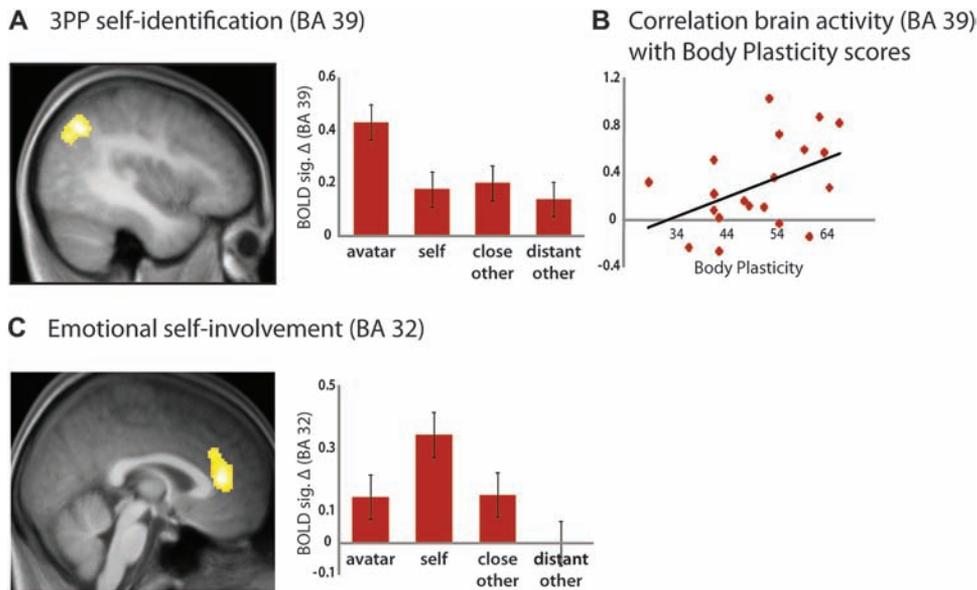
Figure 3. Self-identification with avatars from a third-person perspective. (*A*) Avatar-referencing versus self- and other-referencing yielded greater activity in the left angular gyrus (BA 39), $P < 0.001$ corrected. (*B*) Magnitude of avatar-referential activity in the left angular gyrus (-52, -70, 30) correlated positively with participants' score on body plasticity (24), $r = 0.46$, $P < 0.042$, $n = 20$. (*C*) Avatar-referencing versus familiar distant other-referencing yielded stronger activity within a region of the rACG (2, 38, 12 [BA 32]), $P = 0.030$ corrected. For illustration purposes, graphs are thresholded at $P < 0.001$ uncorrected. Activity is plotted on the average normalized high-resolution anatomical image of participants ($n = 41$) and displayed in neurological convention (left hemisphere is depicted on the left). Bar graphs display mean blood oxygen level–dependent signal change relative to the syllable condition and standard errors. See Supplementary Table S3 for overview of all comparisons.

with which individuals incorporate and self-identify with body enhancements and adornments.

To investigate the hypothesized role of the rACG in players' emotional self-involvement with their avatars, we compared avatar-referencing with close other-referencing and familiar distant other-referencing within a region of the rACG (BA 32; see Materials and Methods). Neural activity in this region was stronger for avatar than for familiar distant other, $t_{95} = 1.90$, $P = 0.030$ corrected (Fig. 3*C*). Additional control comparisons ruled out a mere familiarity effect (see supporting online text in Supplementary Material and Supplementary Table S3). Notably, avatar-referencing rACG activity did not differ from close other-referencing activity in this region, $t_{95} = -0.05$, $P = 0.519$ corrected.

By rating the applicability of presented trait words to the presented person condition (e.g., self, avatar) in the functional magnetic resonance imaging (fMRI) task, participants implicitly associated trait words with each person condition. In the post-scanning task, we investigated this association by a surprise recognition task (one player did not complete the post-scanning recognition memory task. Analysis of recognition memory data included the remaining 21 players). We compared avatar-referent recognition memory, that is, memory for trait words previously presented in the avatar condition ($M = 1.06$, standard deviation [SD] $= 0.42$), to self-referent memory ($M = 1.30$, SD $= 0.42$), close other-referent memory ($M = 1.05$, SD $= 0.42$), and familiar distant other-referent memory ($M = .76$, SD $= 0.39$). Results revealed that avatar-referent memory was worse than self-referent memory, $t_{20} = -3.40$, $P = 0.003$. Interestingly, and as predicted, avatar-referent memory was superior to familiar distant other-referent memory, $t_{20} = 3.10$, $P = 0.006$ (Fig. 4*A*).

Notably, avatar-referent memory did not differ significantly from close other-referent memory, $t_{20} = 0.12$, $P = 0.91$. This

finding is particularly interesting, considering the fact that play duration with the avatar ($M = 2.67$ years, SD $= 1.47$) was approximately half of the duration that gamers had known their close other as their best friend ($M = 5.00$ years, SD $= 2.93$), $t_{20} = -3.91$, $P = 0.001$. Equally notably, and as predicted, avatar-referent memory correlated positively with play duration, $r = 0.49$, $P = 0.03$, $n = 21$ (Fig. 4*B*).

Discussion

By coordinated use of functional neuroimaging, a behavioral encoding-memory paradigm and self-reports, we addressed the neurocognitive basis of human self-identification with avatars from a third-person perspective. Results confirm our hypotheses regarding brain activity and behavior pertaining to 3 features of self-identification with avatars: 1) the third-person perspective, 2) emotional self-involvement, and 3) avatar-related memory.

Relating to the third-person perspective (3PP), our results confirm the predicted functional role of the left angular gyrus in self-identification with external (virtual) bodies that are perceived and controlled from a 3PP. Present findings indicate that avatar-processing in gamers recruited more left angular gyrus activity than processing of self and others (Fig. 3*A*). Control comparisons for this region ruled out a mere familiarity effect, that is, the alternative explanation that gamers perceive their avatar as a familiar animated character (Supplementary Table S3). Interestingly, positive correlations of the magnitude of avatar-referential activity in the left angular gyrus with individual body plasticity levels underscore the pivotal role of this brain region in plasticity to incorporate external body enhancements and external items (e.g., prosthetics and accessories; MacLachlan et al. 2003) into one's bodily identity (Fig. 3*B*).
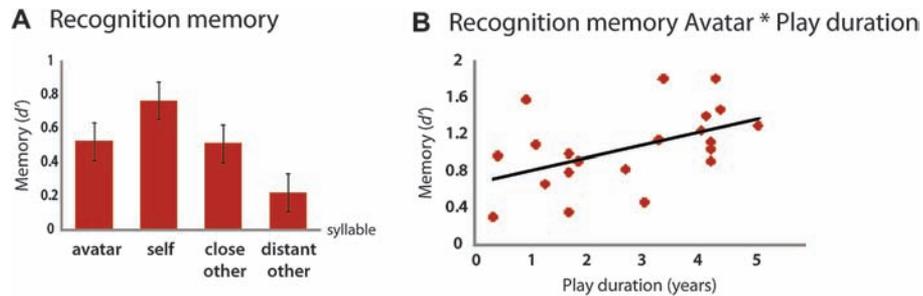
Figure 4. Post-scanning surprise recognition memory performance in players. (*A*) Recognition memory for avatar was superior relative to recognition memory for familiar distant other, $t_{20} = 3.10$, $P = 0.006$. Error bars represent standard errors. (*B*) Avatar memory performance correlated positively with play duration, $r = 0.487$, $P = 0.025$, $n = 21$.

Since only avatar-referential and not other-referential angular gyrus activity significantly covaried with body plasticity, one possibility in line with previous studies (Decety and Grezes 2006; Gazzaniga 2008) is that this form of self-identification, supported by the left angular gyrus, is related to the experience of agency and control over the observed body. The current findings corroborate the possible involvement of the left angular gyrus in processes of self-identification and distinguishing self from others (Decety and Chaminade 2003; Decety and Grezes 2006; Lamm et al. 2007; Gazzaniga 2008), and warrant future research to investigate the exact mechanisms underlying these processes.

One important question concerns how involvement of the left angular gyrus in self-identification with avatars from a 3PP relates to the phenomena of illusory own-body perceptions, such as OBEs (Blanke and Metzinger 2009). Whereas OBEs have been found in association with transient lesions in the right inferior parietal lobe (Blanke et al. 2002, 2005), our results show that avatar-referencing recruits the left inferior parietal lobe. These findings correspond to theories assigning a specialized role of the left hemisphere in retrieval of self-knowledge as well as 3PP own-body recognition (Decety and Grezes 2006; Gazzaniga 2008). Also, as mentioned in the Introduction, whereas OBEs are characterized by a disturbed sense of spatial unity between one's observed own body and oneself as observer (Blanke et al. 2002, 2005; Blanke and Thut 2007; Ehrsson 2007; Lenggenhager et al. 2007), self-identification with the avatar from a 3PP typically involves an appropriation of the observed and controlled avatar body to the gaming self (see Fig. 1; Pearce and Artemesia 2006; Ravaja et al. 2006; Bessière et al. 2007; Yee et al. 2009).

On a phenomenal level, the gamer–avatar dyad may be a mixture between OBEs and a related, yet less well-known illusory body perception called heautoscopy (Blanke et al. 2004; Blanke and Metzinger 2009). In heautoscopy, a condition that is associated with impairments in the left inferior parietal regions, self-location can be either in the physical body or in the illusory second body or in both. This may also be the case in 3PP-gaming, which additionally shares with OBEs the elevated visuospatial perspective from where the physical body is perceived. Future investigations of 3PP-gaming, particularly the switching of self-location between the gamer's physical body and the avatar body as well as bilocation, may inform us further about the intricate interplay between the inferior parietal regions in both hemispheres in confirmatory self-identification, agency, and the dynamics of embodiment.

Relating to gamers' emotional involvement with their avatar, our results support other studies that find a role for the rACG in evaluating one's embodied emotional self-involvement with stimuli under consideration, such as affective pictures, pleasurable rewards (e.g., chocolate), or persons (Damasio 1999; Bush et al. 2000; Gusnard et al. 2001; David et al. 2006; Schilbach et al. 2006; Leknes and Tracey 2008). The greater activity in this region for avatar relative to familiar distant other, but not relative to close other (Fig. 3*C* and Supplementary Table S3), suggests that players are as emotionally involved with their avatar as with a close other. We propose that the experience of acting through an avatar that represents the self (Pearce and Artemesia 2006; Ravaja et al. 2006) creates a level of emotional self-involvement that resembles the level of intimacy one experiences when interacting with a close other (Decety and Grezes 2006; Schilbach et al. 2006; Vanderwal et al. 2008).

With respect to avatar-related memory, the post-scanning recognition memory findings support the notion that long-term gaming enhances gamers' avatar-related memory, a feature of self-identification with one's avatar. Avatar-related memory significantly surpasses memory for familiar distant others (Fig. 4*A*). This raises the tantalizing possibility that acting through an artificial agent in a virtual world yields more advantageous memory strategies than familiarity with a real human distant other.

Recognition memory findings also indicate that the longer gamers play through their avatar, the better their avatar-related memory performance (Fig. 4*B*). Interestingly, memory for avatar did not differ from memory for close other, even though they had known their close other almost twice as long as their avatar. These findings indicate that playing experience with an avatar may yield memory advantages that outweigh the memory strategies associated with real-life interactions with human close others.

Together, the present study illuminates how online virtual worlds may have provided humans with a new mode of self-identification, namely self-identification with avatars that represent the self from a third-person perspective. This new form of self-identification enables humans to build online autobiographical narratives by "acting through somebody," that is, the avatar as seen from a third-person perspective. Acting through the avatar body may facilitate the appropriation of the observed and controlled avatar body to gamers' self-identity. Acting through somebody entails an addition to our current social repertoire of "interacting with somebody," that is, a close other, and merely "observing somebody," usually from a third-person perspective, that is, a familiar distant other. Considering the growing numbers of people that engage in online role-playing, acting through somebody may become an important element of mainstream embodied human social behavior.

Learning, socializing, and developing of new cognitive and affective skills in future human societies may increasingly take place through role-playing with avatars (Gorini et al. 2007; Miller 2007; Rauterberg et al. 2008; Wilson 2008).

In conclusion, our study considerably extends scientific studies of the human experience of self and others by providing a neural window onto the new phenomenon of self-identification with virtual agents from a third-person perspective—a phenomenon that may profoundly change human social experience (Turkle 1995; Bainbridge 2007). The current study also underscores the value of using online virtual reality technologies in addition to immersive virtual reality laboratories to investigate the neural and functional processes underlying different forms of self-identification (Ehrsson 2007; Lenggenhager et al. 2007). The way is now open for future research to make use of these new technologies to advance the neuroscience of the self in the fast changing and increasingly virtual societies of today and tomorrow.

Supplementary Material

Supplementary material can be found at: http://www.cercor.oxfordjournals.org/

Notes

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