

Two Distinct Neuronal Networks Mediate the Awareness of Environment and of Self

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Abstract

■ Evidence from functional neuroimaging studies on resting state suggests that there are two distinct anticorrelated cortical systems that mediate conscious awareness: an “extrinsic” system that encompasses lateral fronto-parietal areas and has been linked with processes of external input (external awareness), and an “intrinsic” system which encompasses mainly medial brain areas and has been associated with internal processes (internal awareness). The aim of our study was to explore the neural correlates of resting state by providing behavioral and neuroimaging data from healthy volunteers. With no a priori assumptions, we first determined behaviorally the relationship between external and internal awareness

in 31 subjects. We found a significant anticorrelation between external and internal awareness with a mean switching frequency of 0.05 Hz (range: 0.01–0.1 Hz). Interestingly, this frequency is similar to BOLD fMRI slow oscillations. We then evaluated 22 healthy volunteers in an fMRI paradigm looking for brain areas where BOLD activity correlated with “internal” and “external” scores. Activation of precuneus/posterior cingulate, anterior cingulate/mesiofrontal cortices, and parahippocampal areas (“intrinsic system”) was linearly linked to intensity of internal awareness, whereas activation of lateral fronto-parietal cortices (“extrinsic system”) was linearly associated with intensity of external awareness. ■

INTRODUCTION

Consciousness has two components, arousal and awareness (Zeman, 2001). Arousal refers to the levels of alertness or vigilance and involves the activity of the brainstem reticular formation, hypothalamus, and basal forebrain, whereas awareness refers to the contents of consciousness and is related to the activity of a widespread set of fronto-parietal associative areas. Awareness and arousal are linearly correlated, in the sense that the less aroused we get the less aware of our surroundings and ourselves we become (Laureys, 2005). Furthermore, awareness encompasses two components: awareness of the environment (external) and of self (internal) (James, 1890). We here define external awareness as the conscious perception of one’s environment through the sensory modalities (e.g., visual, auditory, somesthetic, or olfactory perception). Internal awareness is defined as encompassing mental processes that do not require the mediation of external stimuli or sensory input (e.g., mind wandering, daydreaming, inner speech, mental imagery; for a review, see Lieberman, 2007). Growing neuroscientific evidence supports that the

awareness brain network can be subdivided in two main networks: a fronto-parietal network routinely exhibiting activity increases during attention-demanding cognitive tasks, and a “default network,” which has been involved in self-related processes (Fox et al., 2005).

The aim of the present study is to better characterize the subjective cognitive processes inherent to these “external” and “internal” or “default” networks. We first performed a behavioral experiment looking for the relationship between subjective external and internal awareness scores in 31 healthy volunteers. During an eyes-closed resting condition, subjects were asked to score their external and internal awareness levels by button presses after hearing an auditory prompt. Next, we performed an fMRI experiment in 22 subjects looking for the neural correlates of subjective external and internal awareness scores, correlating external and internal awareness intensity to changes in BOLD neural activity.

METHODS

Before each experiment, subjects received the following instruction: “During the next 15 minutes, we ask you to keep your eyes closed and to avoid prolonged structured thinking, such as counting or singing. When you hear a beep, please use the keyboard to communicate the intensity of

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‘external awareness’ and ‘internal awareness’ ongoing prior to the beep. ‘External’ is here defined as the perception of environmental sensory stimuli (e.g., auditory, visual, olfactory, or somesthetic). ‘Internal’ here refers to all environmental stimuli-independent thoughts (e.g., inner speech, autobiographical memories, or wandering thoughts).”

Participants

Behavioral data were acquired from 31 healthy subjects [21 women, mean (*SD*) age = 26 (3) years]. Imaging data were acquired from 22 healthy subjects, different from the subjects of the behavioral study [10 women, mean (*SD*) age = 23 (2) years]; one participant was excluded from further analysis due to movement artifacts. None of the participants had any relevant medical history or used any centrally acting medication. All participants gave their written informed consent prior to inclusion in the study, which was approved by the Ethics Committee of the University of Liège.

Behavioral Experiment

Our experimental exploration consists of two parts. First, a behavioral experiment was used in order to determine the relationship between external and internal awareness. External and internal awareness scores were recorded using a keyboard. The experiment took place in a quiet room where the subjects were seated comfortably in a chair facing the keyboard. Subjects placed four fingers of both hands (not the thumb) on the keyboard. For the first behavioral study, for the half of the subjects, the left hand corresponded to external awareness (for the other half, the left hand corresponded to internal awareness; randomized order). All subjects were instructed to start responding by using button presses of their left hand on a 4-point scale (0 = absent; 1 = mild; 2 = moderate; 3 = maximal). The subjects’ task was to rate both external and internal awareness (prompted by a 60-dB beep presented via headphones), as defined in the instruction mentioned above. Only when the two scores were given could the next beep be elicited. Interstimulus interval was randomized between 11.3 and 26.8 sec (mean = 19 ± 8 sec). A familiarization session (11 responses) preceded the main experiment (66 responses). Upon completion of the experiment, the content of external and internal awareness was assessed using a semi-structured interview.

Statistical Analysis

The relationship between ratings of external and internal awareness was estimated by calculating Spearman’s *r* correlation coefficients (two-tailed) for every subject and then estimating the mean correlation within the sample. In terms of temporal dynamics, the frequency of switching between

internal and external awareness scores was estimated by first subtracting the external from internal ratings in order to get a unique curve for every subject. The frequency spectrum of these obtained scores was estimated using the Lomb periodogram method for unevenly sampled awareness scores (Press, Flannery, Teukolsky, & Vetterling, 1992; Lomb, 1976).

Imaging Experiment

After having established the relationship between external and internal awareness with the behavioral experiment (using responses from both hands), the fMRI study was performed. Here, in order to reduce the interference with resting state brain function and to reduce motor responses and artifacts to the maximum, behavioral responses were obtained on a single scale reflecting intensity from “more external” to “more internal” awareness. Hence, for the fMRI experiment, awareness scores were recorded with the left hand for all subjects (1 = strongly external, 2 = moderately external, 3 = moderately internal, and 4 = strongly internal). During the scanning period, subjects were asked not to move, to keep their eyes closed, to relax, and to avoid structured thinking (e.g., counting, singing). Subjects were presented an auditory beep, on average, every 20 sec (range = 3–30 sec). After each sound, subjects were asked to evaluate and score by a button press their state of awareness (“strongly external,” “moderately external,” “moderately internal,” and “strongly internal”) for the period preceding the beep. The fMRI study was terminated when on-line analysis showed 15 responses in each state of awareness.

Paired Student’s *t* tests assessed the differences in reaction times between external and internal awareness states. Similarly to the behavioral experiment, the frequency spectrum of awareness scores obtained during the fMRI data was estimated using the Lomb method for unevenly sampled data (Press et al., 1992; Lomb, 1976).

MRI Acquisition

fMRI time series were acquired on a 3-T head-only scanner (Magnetom Allegra; Siemens Medical Solutions, Erlangen, Germany) operated with the standard transmit–receive quadrature head coil. Multislice T_2^* -weighted functional images were acquired with a gradient-echo, echo-planar imaging sequence using axial slice orientation and covering the whole brain (32 slices, FoV = 220×220 mm², voxel size = $3.4 \times 3.4 \times 3$ mm³, 30% interslice gap, matrix size = $64 \times 64 \times 32$, TR = 2460 msec, TE = 40 msec, FA = 90°). The three initial volumes were discarded to avoid T_1 saturation effects. For anatomical reference, a high-resolution T_1 -weighted image was acquired for each subject [T_1 -weighted 3-D magnetization-prepared rapid gradient-echo sequence, TR = 1960 msec, TE = 4.43 msec, inversion time

(TI) = 1100 msec, FoV = $230 \times 173 \text{ mm}^2$, matrix size = $256 \times 192 \times 176$, voxel size = $0.9 \times 0.9 \times 0.9 \text{ mm}^3$].

MRI Analysis

Functional data were preprocessed and analyzed by means of the Statistical Parametric Mapping software SPM5 (www.fil.ion.ucl.ac.uk/spm/software/spm5/; Wellcome Department of Imaging Neuroscience, London, UK), using a two-steps procedure (random effect analysis) that took into account both within- and between-subject variability, as was published elsewhere (Vanhaudenhuyse et al., 2009; Boly et al., 2007). The first two fMRI volumes were removed to allow for signal equilibration. Preprocessing steps included realignment, spatial normalization, and smoothing (Friston, Ashburner, et al., 1995; Friston, Holmes, et al., 1995). The normalization was performed using a three-step automated procedure (Friston, Ashburner, et al., 1995). Firstly, the structural T1 scan of each subject was segmented and normalization parameters were derived from this step from the subject space to the MNI space. Secondly, the functional data were coregistered to the structural scan. Thirdly, the structural and functional scans were normalized using the normalization parameters (voxel size: $2 \times 2 \times 2 \text{ mm}$ for functional and $1 \times 1 \times 1 \text{ mm}$ for structural images) derived from the first step. Functional data were then smoothed using an 8-mm FWHM Gaussian kernel. Each subject's data were modeled individually with a generalized linear model (Friston, Holmes, et al., 1995) and images of effects of interest were produced. These images were then analyzed with a mixed effects model aimed at showing stereotypical effect in the population from which the subjects are drawn (Penny & Holmes, 2003). The mixed effects model was implemented in two processing steps accounting for fixed and random effects, respectively (Boly et al., 2007; Friston, Stephan, Lund, Morcom, & Kiebel, 2005).

For each subject, a first-level intraindividual fixed effects analysis aimed at modeling the data to partition the observed neurophysiological responses into components of interest, confounds, and errors by using a general linear model (Vanhaudenhuyse et al., 2009; Boly et al., 2007; Friston, Holmes, et al., 1995). We created a design matrix using a block design (lasting 3–30 sec) for every individual subject incorporating answers of subjects (“strongly external,” “moderately external,” “moderately internal,” and “strongly internal”) as regressors of interest, time of beeps, reaction time, and movement parameters as supplementary regressors. Reaction times were calculated by subtracting time of answer from time of beep. Movement parameters were derived from realignment of the functional volumes (translations in the x , y , and z directions and rotations around the x , y , and z axes). Reaction times and movement parameters were included as covariates of no interest in the design matrix. A first analysis identified stimulus-induced brain activation in periods rated as “strongly external,” “moderately external,” “moderately internal,” and “strongly in-

ternal.” These periods were incorporated as regressors of interest in the design matrix using a block design (lasting 3–30 sec). The movements were modeled in supplementary regressors. Movement parameters derived from realignment of the functional volumes (translations in the x , y , and z directions and rotations around the x , y , and z axes) were included as covariates of no interest in the design matrix. High-pass filtering using a cutoff period of 128 sec was implemented in the design matrix to remove low-frequency drift from the time series (Vanhaudenhuyse et al., 2009; Boly et al., 2007; Friston et al., 2000). Serial correlations were estimated using a restricted maximum likelihood algorithm with an intrinsic autoregressive model during parameter estimation. The effects of interest were tested through linear contrasts, generating statistical parametric maps (SPM $\{t\}$) in each subject. Contrasts images were computed, identifying a linear positive correlation with external thoughts (1.5 0.5 –0.5 –1.5 contrast of the general linear model parameters) and a linear positive correlation with internal thoughts (contrast –1.5 –0.5 0.5 1.5). The resulting set of voxel values for each contrast constituted a map of t statistic (SPM $\{t\}$) thresholded at $p < .001$ (Peigneux et al., 2006). We then smoothed the contrast images (6 mm FWHM Gaussian kernel) in order to improve statistic across subjects by increasing the overlap between activated areas of each subject, and balancing the existing intersubject anatomical variability (Mikl et al., 2008; White et al., 2001). These smoothed contrast images were entered in a second-level general linear model, acting as a random effects analysis investigating consistent effects at the population level. Statistical inferences were then obtained after correction for multiple comparison at the voxel level using false discovery rate $p < .05$ (whole head volume) for areas previously reported to be involved in internal awareness (i.e., mesiofrontal/anterior cingulate and precuneal/posterior cingulate cortices; Boly et al., 2007; Laureys, Perrin, & Bredart, 2007; Mason et al., 2007), whereas a small volume (8 mm radius sphere) corrected at $p < .05$ (Worsley, 1996) was calculated for areas previously reported to be involved in external awareness (i.e., bilateral posterior parietal and dorsolateral prefrontal cortex; Boly et al., 2007; Haynes, Driver, & Rees, 2005; Dehaene et al., 2001; Vuilleumier et al., 2001), and internal awareness (i.e., mesiofrontal/anterior cingulate and precuneal/posterior cingulate cortices; Boly et al., 2007; Laureys et al., 2007; Mason et al., 2007).

RESULTS

Behavioral Experiment

We observed a significant negative correlation between external and internal awareness scores at the group level (Spearman's $r = -.44$, $p < .02$, two-tailed). At the subject level, 24 participants showed significant negative correlations between internal and external awareness, one showed a positive correlation, and six participants showed

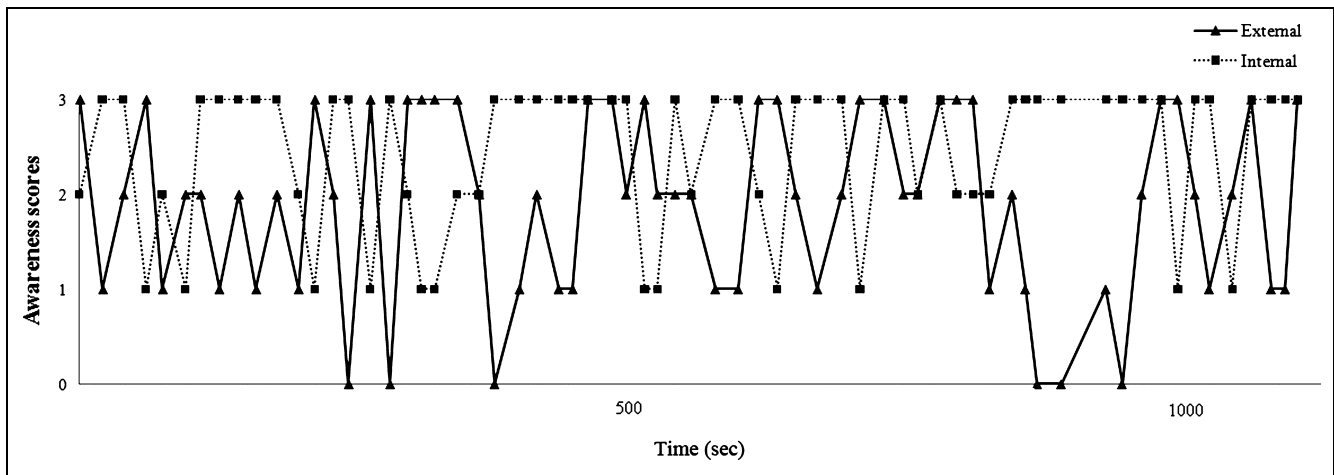


Figure 1. The temporal dynamics of the two components of awareness in a representative subject illustrating that external and internal awareness scores anticorrelate.

nonsignificant correlations. The switching between external and internal awareness was calculated to occur, on average, with a mean frequency of 0.05 ± 0.03 Hz (*SD*) frequency (range = 0.01–0.1 Hz) (Figure 1). External thoughts reported were auditory in 65% of subjects, somesthetic in 58%, olfactory in 13%, and visual in 1%; internal thoughts were experiment-related in 52%, autobiographical in 42%, and inner speech in 13% of subjects. The contents of external and internal awareness are summarized in Table 1.

fMRI Experiment

Scanning was ended when on-line analysis showed at least 15 responses in each state of awareness [mean 18 ± 2 minutes ($X \pm SD$)]. The intensity of internal awareness intensity correlated linearly with activity in posterior cingulate/precuneal, anterior cingulate/mesiofrontal, and bilateral parahippocampal cortices (whole-brain false dis-

covery rate <0.05 ; Figure 2, blue areas; Table 2A). The intensity of external awareness scores correlated linearly with activity in the bilateral inferior frontal gyrus and inferior parietal lobule (small-volume correction; Figure 2, red areas; Table 2B). Additional contrasts looking for linear positive correlations with external thoughts only (1.5 0.5 0 0), independently of a linear positive correlation with internal thoughts only (0 0 0.5 1.5), showed similar results.

Reaction times obtained during the fMRI study did not differ when subjects were in “extrinsic” modes as compared to those obtained during “intrinsic” modes of conscious activity [mean (*SD*) 1352 (1132) msec vs. 1427 (837) msec; $t(20) = 0.72, p = .48$]. The switching between external and internal awareness was calculated (Laguna, Moody, & Mark, 1998) to occur with a mean (*SD*) frequency of 0.03 (0.004) Hz (range = 0.03–0.4 Hz). The mean duration of periods of external [mean (*SD*) = 28 (41) sec] versus internal awareness [29 (66) sec] was not significantly different ($p = .35$).

Table 1. The Contents of the Two Components of Awareness Based on Semi-structured Interview after Completion of the Behavioral Experiment

<i>Content</i>	<i>Number of Subjects (%)</i>	<i>Examples</i>
<i>External</i>		
Auditory	20 (65)	Hearing sounds from outside the room
Somesthetic	18 (58)	Felt itchiness, uncomfortable body posture
Olfactory	4 (13)	Smelling perfume
Visual	2 (1)	Visual perceptions through closed eyelids
<i>Internal</i>		
Experiment-related	16 (52)	Thoughts related to the length of the study
Autobiographical (future and past)	13 (42)	Vacation, plans for weekend
Inner speech	4 (13)	Instruction to oneself to stay vigilant

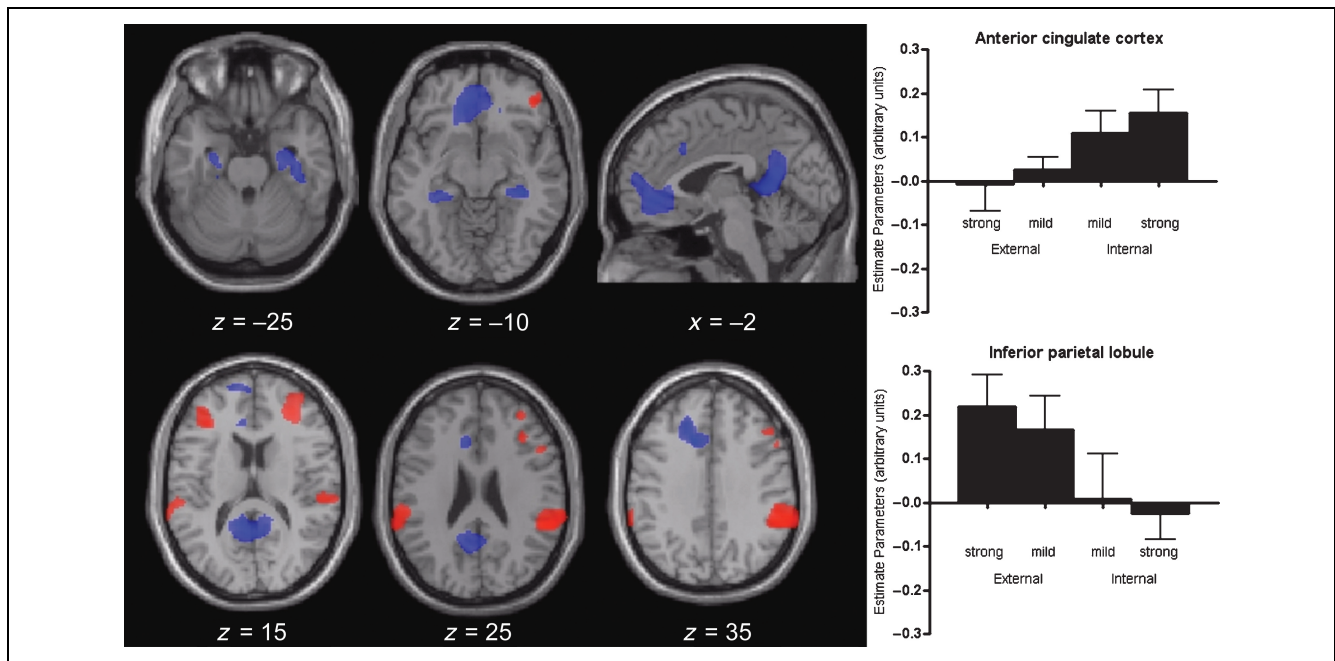


Figure 2. Brain regions showing a correlation between BOLD signal and the intensity of internal and external awareness scores in 22 healthy volunteers. Stronger internal awareness scores correlate with increased activity in anterior cingulate/mesiofrontal, posterior cingulate/precuneal, and parahippocampal cortices (areas in blue). External awareness scores correlate with increased activity in bilateral inferior parietal lobule and dorsolateral prefrontal cortices (in red).

DISCUSSION

Growing neuroscientific evidence supports the idea that the brain's intrinsic or default activity is essential to its global functioning (Raichle & Snyder, 2007). This notion was initially stressed by positron emission tomography studies, which revealed metabolic decreases in specific brain areas (e.g., posterior cingulate/precuneal and ante-

rior cingulate/medial–prefrontal cortices) during performance of specific cognitive tasks as compared to passive resting state (Shulman et al., 1997). Raichle and Snyder (2007) and Raichle et al. (2001) considered these “deactivations” as deviations from an ongoing metabolic/physiologic baseline which characterizes the functionality not only of the aforementioned areas, the so-called default network, but also of most areas of the brain. Searching for joined

Table 2. Peak Voxels of Brain Areas Showing a Positive Correlation with Intensity of External and Internal Awareness

Region	x (mm)	y (mm)	z (mm)	Z	p
<i>(A) Internal</i>					
PCC/precuneus	-10	-42	8	4.68	<.0001 ^a
ACC/mesiofrontal	-12	20	38	5.01	<.0001 ^a
Left parahippocampal	-24	-18	-20	3.87	<.0001 ^a
Right parahippocampal	38	-30	-10	4.76	<.0001 ^a
<i>(B) External</i>					
R Inferior frontal gyrus	38	44	4	2.66	.004 ^b
L Inferior frontal gyrus	-36	32	16	2.25	ns (.012)
R Inferior parietal	60	-42	32	2.86	.002 ^b
L Inferior parietal	-58	-30	22	2.49	ns (.006)

R = right; L = left; PCC = posterior cingulate cortex; ACC = anterior cingulate cortex; ns = nonsignificant.

^aFalse discovery rate corrected.

^bSmall-volume corrected (8 mm radius sphere centered on previously published coordinates).

activations in this “default state,” two meta-analyses of positron emission tomography activation protocols with healthy subjects revealed that a network of frontal and parietal heteromodal associative cortices was more active at rest as compared to other cognitive tasks (Mazoyer et al., 2001; Shulman et al., 1997). Such evidence led to the assumption that the brain at rest is not silent. On the contrary, the brain’s activity at rest is characterized by spontaneous low-frequency fluctuations, in the range of 0.01–0.1 Hz, which can be detected in the BOLD signal of the fMRI measurement in “resting” conditions. These spontaneous BOLD fluctuations cannot be attributed to peripheral noise (e.g., cardiac and respiratory fluctuations, motion of the subject) but show synchronized activity with other functionally related brain regions (Fox & Raichle, 2007; Cordes et al., 2000). In particular, it is suggested that the brain’s baseline activity is organized in two widespread brain networks: “extrinsic” and “intrinsic” (Boly et al., 2007; Fox & Raichle, 2007; Golland et al., 2007; Tian et al., 2007; Fox et al., 2005; Fransson, 2005; Cordes et al., 2000). The extrinsic system encompasses lateral fronto-parietal areas, resembling the brain activations during goal-directed behavior, and it has been linked to cognitive processes of somatosensory (Boly et al., 2007; Bornhovd et al., 2002; Buchel et al., 2002), visual (Fuhrmann, Hein, Tsai, Naumer, & Knight, 2008; Rees, 2007), and auditory (Fuhrmann et al., 2008) external sensory input. The intrinsic system encompasses mainly medial brain areas, is similar to the activity of the default network, and has been associated with cognitive processes such as mind wandering or daydreaming (Mason et al., 2007; McKiernan, D’Angelo, Kaufman, & Binder, 2006), mental imagery (Knauff, Fangmeier, Ruff, & Johnson-Laird, 2003), inner speech and self-oriented thoughts (Goldberg, Harel, & Malach, 2006; Lou et al., 2004).

The present study aimed to bridge the gap between our knowledge on default resting state neural networks as assessed by fMRI and their subjective cognitive counterparts. In our behavioral experiment, we showed a negative correlation between external and internal awareness scores in nearly 80% of the studied subjects (24 out of 31 participants). It should be noted that despite the significant anticorrelation between external and internal modes of conscious processing at the group level, there seems to exist a substantial variability at the individual subject level. Future studies could correlate this variability of conscious content with personality traits (e.g., from normal controls to “schizoid” subjects with dissociative contents of consciousness). We also showed a periodic shift from external to internal awareness occurring, on average, every 20 sec (0.05 Hz), corresponding to the spontaneous low-frequency fluctuations (range of 0.01–0.1 Hz) previously reported (Fox & Raichle, 2007; Cordes et al., 2000). Engagement to demanding self-oriented tasks makes us less receptive to environmental stimuli (James, 1890) and this switch in attention can happen without conscious recognition (Smallwood & Schooler, 2006). In the absence of conscious

control, human minds like to wander during both resting periods and heavily loaded cognitive tasks (Giambra, 1995; Antrobus, 1968). Such stimulus-independent thoughts are reported significantly more often during rest than when performing externally oriented tasks (e.g., tone detection task; Filler & Giambra, 1973) and during tasks that are overlearned as compared to novel ones (Goldberg et al., 2006). This unconstrained mental activity was shown to impair signal detection (Giambra, 1995; Singer, 1993), reading (Antrobus, 1968), detailed encoding (Teasdale et al., 1995), and sustained attention tasks (Duval & Wicklund, 1972). In this sense, psychological research suggests that deprivation of external sensory input may result in an increase of internally generated activity (Smallwood, McSpadden, & Schooler, 2008; Schooler, Reichle, & Halpern, 2005; Schooler, 2002; Giambra, 1995). However, clinical cases such as Charles–Bonnet syndrome (i.e., visually impaired patients that experience visual illusions) might counterbalance these findings (Kester, 2009).

Our fMRI study showed a link between the intrinsic and extrinsic brain networks and spontaneous mentation. In the fMRI experiment, subjects’ reports of being “strongly externally aware” correlated with activation in the “extrinsic system” (i.e., lateral fronto-parietal areas) and reports of being “strongly internally aware” correlated with activation in the “intrinsic system” (i.e., medial brain areas). Our data are in line with previous studies showing the competing character of the two systems in the sense that these two systems can disturb or even interrupt one another (Tian et al., 2007; Weissman, Roberts, Visscher, & Woldorff, 2006), illustrated also by studies on motor performance (Fox, Snyder, Vincent, & Raichle, 2007), perceptual discrimination (Sapir, d’Avossa, McAvoy, Shulman, & Corbetta, 2005), attention lapses (Weissman et al., 2006), and somatosensory perception of stimuli close to sensory threshold (Boly et al., 2007). These studies have shown that high prestimulus baseline activity in the intrinsic system is associated with a tendency to ignore environmental stimuli, whereas perceived external stimuli were associated with an increased activity in the extrinsic system. The predictive value of the prestimulus baseline activity to behavior has been also shown by studies with EEG (Sapir et al., 2005) and magnetoencephalography (Linkenkaer-Hansen, Nikulin, Palva, Ilmoniemi, & Palva, 2004). It should be noted that, to date, no definite answer can be given as to whether these two systems constitute the causal correlates of internal and external awareness. The sufficiency and necessity of these two components to consciousness remains to be further explored by, for example, transcranial magnetic stimulation lesion protocols or other more invasive methodologies.

Although it has been suggested that the low-frequency fluctuations observed at resting state reflect nothing but vascular processes (Lamme, 2003), others support that they refer to conscious mentation (Goldberg et al., 2006). According to our results, collected via a semi-structured interview, the content of spontaneous thought was preferentially

autobiographical and referred to mental images, reminiscent of past experiences and plan making, which correspond to accumulating data that the default network is mediating self-related processes (Golland, Golland, Bentin, & Malach, 2008; Addis, Wong, & Schacter, 2007; Li, Yan, Bergquist, & Sinha, 2007; Mitchell et al., 2007; Hester, Foxe, Molholm, Shpaner, & Garavan, 2005; Naghavi & Nyberg, 2005; Sapir et al., 2005; Otten & Rugg, 2001). Several other explanations have been introduced for the functional role of the resting state, such that it reflects spontaneous thoughts (Buckner & Carroll, 2007) or that it accounts for the monitoring of the external world (for a review, see Hahn, Ross, & Stein, 2007). Nevertheless, the pervasiveness of the default network after general anesthesia in monkeys (Vincent et al., 2007), in vegetative state (only cortico-cortical connectivity), and its absence in brain death (Boly et al., 2009), reflects a fundamental intrinsic property of the brain's organization that seems to transcend the levels of consciousness (Boly et al., 2009; Buckner, Andrews-Hanna, & Schacter, 2008). Future studies could apply the presented methodology to modified states of consciousness such as hypnosis. We hypothesize that in hypnotic resting state, internal and external modes would be dissociated with a predominance of intrinsic network activity.

The critical role of the extrinsic and intrinsic systems to consciousness is well illustrated in cases of impaired conscious states. For example, in the vegetative state (a state of arousal without awareness, Laureys, 2005), systematic metabolic dysfunctions have been identified in a wide fronto-parietal network encompassing the bilateral lateral and frontal regions, the bilateral parieto-temporal and posterior parietal areas, posterior cingulate cortex, and the precuneus (Laureys, 2005; Laureys et al., 1999). In addition, disconnections between latero-frontal and midline posterior areas and between thalamic nuclei and lateral and medial frontal cortices have been also found in vegetative patients (Laureys et al., 1999, 2000). The lack of external and internal awareness is observed not only in these patients but also in slow-wave sleep (Maquet et al., 2005) and in general anesthesia (Kaisti et al., 2003), whereas they resume their functionality during REM sleep (Maquet et al., 2005), supporting our findings.

In conclusion, our data shed light on the neural correlates of awareness' two major dimensions: external or environmental awareness relating to activity in lateral fronto-parietal associative networks and internal awareness relating to midline "default" networks. The study of the functional integrity of these two interdependent brain networks may offer clinical interest in our search for neural markers of awareness in health and disease (e.g., coma and related "vegetative" states).

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