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Susceptibility to everyday cognitive failure is reflected in functional network interactions in the resting brain

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ABSTRACT

The proneness to minor errors and slips in everyday life as assessed by the Cognitive Failures Questionnaire (CFQ) constitutes a trait characteristic and is reflected in stable features of brain structure and function. It is unclear, however, how dynamic interactions of large-scale brain networks contribute to this disposition. To address this question, we performed a high model order independent component analysis (ICA) with subsequent dual regression on resting-state fMRI data from 71 subjects to extract temporal time courses describing the dynamics of 17 resting-state networks (RSN). Dynamic network interactions between all 17 RSN were assessed by linear correlations between networks' time courses. On this basis, we investigated the relationship between subject-level RSN interactions and the susceptibility to everyday cognitive failure. We found that CFQ scores were significantly correlated with the interplay of the cingulo-opercular network (CON) and a posterior parietal network which unifies clusters in the posterior cingulate, precuneus, intraparietal lobules and middle temporal regions. Specifically, a higher positive functional connectivity between these two RSN was indicative of higher proneness to cognitive failure. Both the CON and posterior parietal network are implicated in cognitive functions, such as tonic alertness and executive control. Results indicate that proper checks and balances between the two networks are needed to protect against cognitive failure. Furthermore, we demonstrate that the study of temporal network dynamics in the resting state is a feasible tool to investigate individual differences in cognitive ability and performance.

Introduction

An individual's susceptibility to everyday cognitive failure such as confusing left and right, forgetting where you put your keys or failing to notice signposts shows considerable variability across people. To quantify these differences in proneness to slips and minor mistakes, the *Cognitive Failures Questionnaire* (CFQ) has been developed (Broadbent et al., 1982). Recent research indicates that the CFQ score constitutes a trait characteristic (Bridger et al., 2013) with a clear genetic underpinning ($h^2 = .50$; Boomsma, 1998; Markett et al., 2014). It is hence assumed that an individual's susceptibility to everyday cognitive failure as measured by the CFQ is reflected in stable features of brain structure and function. While the CFQ score has been linked to brain anatomy (Kanai et al., 2011) and brain activity during cognitive tasks (Garavan et al., 2002; Hester et al., 2004), its relation to functional connectivity networks has not been studied, yet.

The human brain is organised into a collection of functional networks that flexibly interact to support various cognitive functions (Fair et al., 2009). This functional organisation is reflected in patterns of coherent spontaneous activity fluctuations in different regions of the brain, which can be measured via resting-state fMRI (rs-fMRI). Connectivity focused analyses of resting-state data have yielded a number of resting-state networks (RSN) which appear to be stable across subjects and time (Damoiseaux et al., 2006). Beyond this overall consistency of topographical features, between-subject variability in spatial network characteristics relating to the involvement of specific brain regions in certain RSN have been linked to various psychiatric disorders, as well as to differences in task performance and behavioural traits (Vaidya and Gordon, 2013). Similarly, variability in the brain's resting activity may be associated with differences in the proneness to cognitive failure. While the multiform nature of everyday slips and errors makes it

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difficult to study their neurophysiological correlates directly using specific tasks, rs-fMRI may provide a promising new approach to investigate their biological basis.

A well-established method to identify RSN from spontaneous BOLD fluctuations is Independent Component Analysis (ICA). The data-driven ICA algorithm decomposes the entire BOLD data set into components that are maximally independent in a statistical sense (Beckmann and Smith, 2004). Each of the resulting components represents a set of voxels that show similar patterns of spontaneous BOLD fluctuations. Hence, each component is characterised by a spatial map and a specific time course. While some components reflect noise artefacts, others can be classified as RSN. The list of widely replicated RSN comprises the Default Mode Network (DMN), two lateralised frontoparietal networks (left and right FPN), the dorsal attention network (DAN), the cingulo-opercular network (CON), the cerebellar network (CEN), the sensorimotor network, at least two visual networks etc. (Smith et al., 2009; for a review see van den Heuvel and Hulshoff Pol, 2010).

In task-based fMRI studies, elevated activation levels of these networks have been linked to specific functions. In this context, a special focus is placed on the distinction between "task-positive" and "task-negative" networks (Fox et al., 2005). Whereas task-positive networks like the DAN exhibit an increased BOLD response when participants engage in tasks demanding executive control and processing of external stimuli, brain regions involved in the DMN are less activated during task performance, as compared to task-free baseline conditions. In accordance with this common observation, activity in the DMN is associated with internally focused cognition including daydreaming, autobiographical memory retrieval and envisioning the future (Buckner et al., 2008). Interestingly, the antagonism between task-positive networks and the DMN is also apparent in the resting state: while the BOLD time series within each network are positively correlated, correlations between time series of the DMN and task-positive networks are negative (Fox et al., 2005; Fransson, 2005). Recent research points towards the functional significance of this antiphase relationship between task-positive and task-negative networks in the resting brain. Between-subject variability in network antagonism – expressed as the strength of the negative correlation between the networks' time series – has been related to the efficiency of the regulation of attentional processes (Kelly et al., 2008) and to inhibition errors in the Go/NoGo task (Barber et al., 2013). In both studies, a stronger network antagonism proved beneficial for cognitive performance.

While the DMN and its antiphase relationship with task-positive networks has been in the focus of many recent studies, interaction patterns between other RSN and their functional significance have not been investigated extensively, yet. Especially, only a few studies have used ICA-derived time series as opposed to seed-based correlations, to analyse between-network interactions (Tian et al., 2013). In the widely used seed region approach, the mean BOLD time series from one hub region in one network is correlated with the time course from another network's hub region. While this approach to rs-fMRI datasets has the merit of being easy to interpret (Fox and Raichle, 2007), it comes with the downsides that the temporal properties of multiple hub regions within one network cannot be adequately captured, and that the resulting RSN depend on the (often arbitrarily) selected seed regions. ICA has been proposed as an alternative tool to derive RSN based on the data alone and without biasing the results towards a-priori defined seed regions. Despite the growing popularity of ICA, in most applications only the spatial maps of the acquired RSN, which reflect the involvement of distinct brain regions, are used to identify differences between subjects (e.g. Greicius et al., 2004, 2007), and the associated time series are neglected. However, patterns of between-network interaction derived from the temporal features of the independent components may prove useful to explain between-subject differences. Therefore, we propose the use of the component time series as derived from ICA to study RSN interactions and their role in individual differences in behaviour and behavioural disposition.

The aim of the present study was to investigate whether the susceptibility to everyday cognitive failure is related to network interactions in the resting brain. To that end, an ICA was performed on rs-fMRI data from 71 subjects to derive 70 independent components. After the ICA, a dual regression approach was applied to find subject-level versions of the components' spatial maps, along with associated time series (see Section 2.4). For further analyses, the components were classified either as noise artefacts or as RSN. Using their specific time series, interaction patterns between RSN as well as their associations with the CFQ score were analysed.

In order to realise the full potential of the ICA approach, we aimed at exploring the effects of all RSN interactions obtained. Therefore, each of the between-network interactions was correlated with the CFQ scores. Based on previous findings regarding the efficiency of attention regulation and inhibitory control (Kelly et al., 2008; Barber et al., 2013), which contribute to an individual's error proneness in terms of an underlying cognitive control capacity (Bridger et al., 2013), reduced negative correlations between task-positive networks and the DMN were hypothesised to be associated with higher cognitive failure scores on the CFQ.

Materials and methods

Participants and measures

A total number of $N = 71$ subjects (80.3 % female; mean age $M = 21.56$, $SD = 3.28$) participated in the present study after their informed written consent was obtained. The high proportion of females reflects the high percentage of females among psychology students, from where participants for the present study were recruited. None of the participants had a history of neurological or psychiatric disorders as assessed by a short screening questionnaire, and all were free of contraindications to MRI. The study protocol was in accordance with the Declaration of Helsinki and approved by the local ethics committee of the University Hospital Bonn. All subjects took part in the Bonn Gene Brain Behavior Project (BGBBP). Upon recruiting, they filled in the German version of the CFQ (Klumb, 1995) as part of a larger battery of questionnaires, which were investigated in the context of other studies. The German version of the CFQ consists of 32 items, each presenting a brief scenario of perceptual ("Do you fail to listen to people's names when you are meeting them?"), memory ("Do you find you forget why you went from one part of the house to the other?") or psychomotor failure ("Do you bump into people?"). Using a five-point Likert scale (ranging from "0 = never" to "4 = very often"), participants stated how often each of the mentioned events happened to them in the past six months. A sum score was computed for each subject.

Image acquisition

MRI sessions were scheduled at least two weeks after CFQ application, with a median delay of approximately three months. All resting-state data were acquired in the context of several more extensive fMRI studies, including a decision making paradigm and an affective picture perception task in the majority of cases. Resting-state data were always acquired after task data. Of note, none of the tasks involved executive control demands, which might have primed thoughts about one's own cognitive abilities.

From each participant, 245 T2*-weighted volumes were obtained on a Siemens Avanto 1.5 T scanner (Siemens, Erlangen, Germany) at the Life & Brain Center Bonn in a single session lasting approximately twelve minutes. Each volume consisted of 38 slices (thickness: 3 mm, interslice gap: 1 mm, in-plane resolution: 3×3 mm^2) scanned ascending in interleaved order (TR: 3.04 s, TE: 45 ms, Flip Angle: 90°, Field of View: 192 mm). Participants were instructed to lie as still as possible with their eyes closed, thinking of nothing in particular and without falling asleep.