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Neurophysiological basis of creativity in healthy elderly people: A multiscale entropy approach

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HIGHLIGHTS

- The first study on creativity in healthy elderly people by assessing resting state EEG complexity with multiple temporal scales using multiscale entropy.
- Higher individual creativity was linked to the increased EEG complexity particularly in lower frequencies.
- Our findings underscore the potential usefulness of multiscale entropy analysis for characterizing the neurophysiological basis of creativity.

ABSTRACT

Objectives: Creativity, which presumably involves various connections within and across different neural networks, reportedly underpins the mental well-being of older adults. Multiscale entropy (MSE) can characterize the complexity inherent in EEG dynamics with multiple temporal scales. It can therefore provide useful insight into neural networks. Given that background, we sought to clarify the neurophysiological bases of creativity in healthy elderly subjects by assessing EEG complexity with MSE, with emphasis on assessment of neural networks.
Methods: We recorded resting state EEG of 20 healthy elderly subjects. MSE was calculated for each subject for continuous 20-s epochs. Their relevance to individual creativity was examined concurrently with intellectual function.
Results: Higher individual creativity was linked closely to increased EEG complexity across higher temporal scales, but no significant relation was found with intellectual function (IQ score).
Conclusions: Considering the general "loss of complexity" theory of aging, our finding of increased EEG complexity in elderly people with heightened creativity supports the idea that creativity is associated with activated neural networks.
Significance: Results reported here underscore the potential usefulness of MSE analysis for characterizing the neurophysiological bases of elderly people with heightened creativity.

1. Introduction

Creativity is closely linked to divergent thinking (Guilford, 1967), which does not appear to depend strongly on any single mental process. Creativity requires diverse high-level cognitive functions that are useful to integrate existing knowledge and to create something of value. Creative activities have become widely adopted at facilities for elderly people. Positive relations between creativity and the mental well-being of older adults have been reported (for reviews, see Cohen, 2006; McFadden and Basting, 2010). However, studies that have investigated the neurophysiological bases for creativity, particularly addressing elderly subjects, have rarely been reported.

Creative activities are assumed to involve various regions in the brain and are expected to be accomplished under the activation of

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neural networks. An increasing number of studies have supported the inference that various brain regions are involved in creativity (for reviews, see Arden et al., 2010; Dietrich and Kanso, 2010; Jung et al., 2013). Furthermore, analyses of resting state electroencephalography (EEG) and functional MRI (fMRI) reportedly provide useful insight into intrinsic neural network mechanisms for creativity (Heilman et al., 2003; Jung et al., 2013).

Neural networks are characterized by dynamical neural communications in functionally specialized assemblies and long-range mutual interactions across these assemblies (Varela et al., 2001; Schnitzler and Gross, 2005; Barabasi, 2009; Sporns, 2011). Output neurophysiologic signals derived from EEG therefore exhibit complex temporal fluctuations that reflect nonlinear dynamical processes (Tononi et al., 1998; Abarbanel and Rabinovich, 2001). To explore the relation of EEG complexity to neuronal networks, Friston (1996) assessed the effect of the degree of neural connectivity and measures of complexity using synthetic neuronal models, finding that progressive disconnection increases EEG signal complexity. Consequently, the recent advent of EEG complexity quantification using nonlinear methods has presented a new avenue for ascertaining the intrinsic neural network mechanisms that underlie the various neurophysiological processes (Stam, 2005; Takahashi, 2013). However, classical complexity measures (e.g., Kolmogorov–Sinai entropy, correlation dimension or Lyapunov exponent) require numerous data points and stationary noise-free time series for reliable estimation (Grassberger and Procaccia, 1983; Smith, 1988; Eckmann and Ruelle, 1992). By contrast, approximate entropy (ApEn (Pincus, 1991, 2001)) and its modified version, sample entropy (SampEn (Richman and Moorman, 2000; Richman et al., 2004)), are robust to noise and finitude of datasets, which are unavoidable in experimental data. Furthermore, because brain activity (i.e., EEG activity) consists of both stochastic and deterministic processes (Fell et al., 2000), ApEn and SampEn might be better suited to this type of composite signal with good reproducibility (Pincus, 2001; Costa et al., 2005), whereas other classical complexity measures have been developed for, and are more properly employed on, output derived from chaotic processes that are inherent in deterministic dynamical systems.

Because brain dynamics are influenced both by local dense interconnectivity and long-range excitatory projections (Friston et al., 1995; Tononi et al., 1998), the resulting dynamics can be expected to operate at multiple temporal scales (Takahashi, 2013). In practice, specific frequency bands might have their own different functional roles. Several rhythms can coexist temporally (Klimesch, 1999; von Stein and Sarnthein, 2000; Varela et al., 2001). Considering that creativity is assumed to involve various connections within and across different neural subsystems in the brain (Kowatari et al., 2009; Dietrich and Kanso, 2010; Jung et al., 2013), the output EEG signals from these complex neural networks must be characterized with different time scales or frequencies. However, previous studies that explored the relevance of creativity and EEG complexity have remained limited to the scope of multiple temporal scales (Molle et al., 1996, 1999; Jausovec and Jausovec, 2000a; Krug et al., 2003). To investigate the variation in physiological signals across multiple temporal scales, Costa et al. (2002) introduced multiscale entropy (MSE), which is calculated based on SampEn, in recognition of the likelihood that dynamical complexity of biological signals might operate across a range of temporal scales. Our previous studies have demonstrated the utility of MSE in exploring EEG changes with aging (Takahashi et al., 2009), schizophrenia (Takahashi et al., 2010), depression (Okazaki et al., 2013), and Alzheimer's disease (Mizuno et al., 2010). Therefore, the evaluation of EEG complexity using MSE analysis might be a promising method for elucidating neural network mechanisms.

This study was designed to clarify the neurophysiological basis of creativity in healthy elderly subjects in the light of neural networks. We investigated resting state EEG complexity using MSE analysis and examined their relevance to individual creativity.

2. Methods

2.1. Subjects

Twenty healthy elderly people (11 men, 9 women) who willingly volunteered for the study were recruited from a local community of Fukui prefecture. They were right handed, with mean age of 71.5 years (61–81, SD: 4.8). All subjects were medication-free. Subjects with major medical or neurological conditions, including epilepsy or head trauma in the past, a lifetime history of alcohol or drug dependence, internal disease including hypertension, and hyperlipidemia or diabetes mellitus, were excluded. Conventional MRI was performed to exclude subjects with major brain abnormalities. In addition, subjects with scores on the Mini-Mental State Examination (Folstein et al., 1975) lower than 28 were excluded. After a complete explanation of the study, written informed consent was obtained from each subject. The Ethics Committee of the University of Fukui approved the study protocol.

2.2. Creativity assessment

Creativity assessments were conducted using the S–A creativity test (Society for Creative Mind, 1969), Version C, which has been used for the assessment of individual trait creativity since it was published in 1993. The test, which was produced by J.P. Guilford to assess the power of divergent thinking and which was standardized for Japanese speakers, was used to evaluate creativity. The test includes tasks of three types. The first task requires subjects to generate unique ways of using typical objects. The second task requires subjects to imagine desirable functions in ordinary objects. The third task requires subjects to imagine the consequences of an unexpected event. Each task requires subjects to generate as many answers as possible in less than 5 min. The test is scored by each of four characteristic traits: fluency, flexibility, originality, and elaborate thinking. These four dimensions correspond to the same concepts as those of the Torrance test of creative thinking (Torrance, 1966), which is applied extensively in the study of neurobiology (for reviews, see Arden et al., 2010; Dietrich and Kanso, 2010). The S–A creativity test has also been used in the study of neurobiology, although the reported studies are fewer. Takeuchi and co-workers described the significant associations of the S–A creativity test score and resting state functional connectivity using fMRI (Takeuchi et al., 2012), the effects of working memory training on functional connectivity (Takeuchi et al., 2011c), brain activity (Takeuchi et al., 2011b), cerebral blood flow (Takeuchi et al., 2011a), and structural changes (Takeuchi et al., 2011c, 2010a,b). According to these reports, the S–A creativity test score was used as a degree of individual creativity in this study.

2.3. IQ assessment

Intelligence quotient (IQ) assessments were conducted using a general test, the Wechsler Adult Intelligence Scale-III (WAIS-III; Wechsler, 1997). Each full-scale IQ score was used in the analysis of this study.

Table 1 presents information reported for high-creativity and low-creativity subjects across sex, age, S–A creativity test score, and full-scale IQ score.