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Fluid intelligence and neural efficiency: effects of task complexity and sex

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Abstract

On the basis of the *neural efficiency* concept of human intelligence—which suggests a more efficient use of the cortex (or even the brain) in brighter individuals—we analyzed the role of sex and task complexity as possible moderating variables in the relationship between cortical activation and psychometric intelligence. In 28 males and 30 females we measured cortical activation in the EEG during performance of a modified variant of Stankov's Triplet Numbers test—a test consisting of five increasingly complex conditions. Preliminary analyses showed that both sex- and intelligence-related effects on cortical activation became more evident when we focused on participants' fluid intelligence scores instead of just using scores of general mental ability. As expected, we observed an increase of cortical activation with increasing task complexity, but no moderating influence of task complexity on the intelligence-activation relationship was found. Moreover, our data suggest that the males were more likely to produce cortical activation patterns in line with the *neural efficiency* hypothesis (i.e. less activation in brighter individuals), whereas in females no significant differences were found.

Keywords: Intelligence; Fluid intelligence; Complexity; Reaction times; EEG; Event-related desynchronisation; Sex differences; Neural efficiency

Neuroimaging techniques like the measurement of the brain's glucose metabolism rate (GMR) using positron emission tomography (PET) have produced empirical evidence of a more strongly localized cortical activation during cognitive task performance in brighter as compared to less intelligent individuals (Haier, Siegel, MacLachlan et al., 1992; Haier et al., 1988; Haier, Siegel, Tang, Abel, & Buchsbaum, 1992; Parks et al., 1988). This more strongly focused cortical activation (resulting in a lower total cortical activation) in brighter as compared to less intelligent individuals is often interpreted within the so-called *neural efficiency* hypothesis that suggests a

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more efficient use of the cortex (or even the brain) in brighter as compared to less intelligent individuals—presumably they ‘‘use only a limited group of brain circuits and/or fewer neurons, thus requiring minimal glucose use’’ (Haier, Siegel, MacLachlan et al., 1992, p. 134).

Evidence in favor of the *neural efficiency* hypothesis comes also from other psychophysiological measurement methods which focus on the extent of ‘‘Event-Related Desynchronization (ERD) in the human EEG (Neubauer, Freudenthaler, & Pfurtscheller, 1995; Neubauer, Sange, & Pfurtscheller, 1999; Neubauer, Fink, & Schrausser, 2002; cf. also Jausovec, 1996, 1998; Jausovec & Jausovec, 2001) or from EEG studies dealing with evoked brain potentials (Deary & Caryl, 1993) or studies using slow potential topography (Lamm, Bauer, Vitouch, & Gstättner, 1999; Vitouch, Bauer, Gittler, Leodolter, & Leodolter, 1997).

Contrary to the PET imaging method that only shows cumulative brain functions over the whole uptake phase (i.e. several minutes), the measurement of the so-called ‘‘Event-Related Desynchronzation’’ in the human EEG (originally proposed by Pfurtscheller & Aranibar, 1977; for a more detailed description of the ERD method see Pfurtscheller & Lopes da Silva, 1999), a well-established measure, which is based on the well-known phenomenon of a blocking (or desychronization) of rhythmic EEG-background activity within the alpha band (from 7.5 to 12.5 Hz), provides a more fine-grained temporal analysis of brain activation and seems, therefore, especially suited for the study of short-lasting (i.e. phasic) changes of cortical activation—which might be necessary when focusing on physiological correlates of elementary cognitive processes.

In several studies the ERD method has proven a useful and appropriate method to measure the level and topographical distribution of cortical activation during cognitive task performance (e.g. implicit and explicit learning: Zhuang et al., 1997; memory performance: Klimesch, 1999; Krause, Sillanmäki et al., 2000; visual information processing: Pfurtscheller, Neuper, & Mohl, 1994). In addition to this, the ERD method might even be used as an indicator of localized brain activation in affective (emotional) tasks (see e.g. Aftanas, Koshkarov, Pokrovskaja, Lotova, & Mordvintsev, 1996; Krause, Viemerö, Rosenqvist, Sillanmäki, & Aström, 2000). We employed the ERD method in order to analyze the relationship between IQ and the level and topographical distribution of cortical activation during performance of several elementary cognitive tasks, which have been frequently used in the mental speed approach to human intelligence. For instance, in the Neubauer et al. (1999) study we related cortical activation patterns during performance of Posner's classical letter matching task to psychometrically determined intelligence. In this task (cf. Posner & Mitchell, 1967) the participants are shown letter pairs on each trial, which in a simple condition have to be judged regarding the physical identity (PI) of the presented stimuli, whereas in a more complex Name Identity (NI)-condition the semantic identity of the letters has to be assessed.

In analyzing the extent of Event-Related Desynchronization (ERD) in the EEG during performance of Posner's letter matching test (cf. Neubauer et al., 1999) we found the more complex semantic comparisons (NI) generally evoking stronger ERDs as compared to the relatively simple physical comparisons (PI). Similar effects of task complexity on cortical activation patterns have been observed by Dujardin, Bourriez, and Guieu (1995) and by Wilson, Swain, and Ullsperger (1999).

In the present study we intend to further analyze the effects of task complexity on the level of cortical activation by not only comparing two but up to five levels of task complexity. In this context we are primarily interested in the possible moderating role of task complexity on the