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Cerebral lateralization and general intelligence: Gender differences in a transcranial Doppler study

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Abstract

The present study evaluated cerebral lateralization during Raven's progressive matrices (RPM) paradigm in female and male subjects. Bilateral simultaneous transcranial Doppler (TCD) ultrasound was used to measure mean blood flow velocities (MBFV) in the right and left middle cerebral arteries (MCAs) in 24 (15 females and 9 males) right-handed normal subjects. The female subjects used a left hemisphere strategy, while males used a right hemisphere strategy to successfully solve RPM tasks. This implies that general intelligence is associated with neural systems within one hemisphere that are accessible to a variety of cognitive processes.

Keywords: Cognition; Language; Cerebral blood flow; Ultrasound; Brain; Sex; Psychological tests; Laterality

1. Introduction

The determinants of human performance have been a subject of intense debate for over a century. Spearman in 1904, put forward the idea that measures of performance or success in diverse cognitive tests show a pattern of almost universal positive correlation (Jensen, 1987; Spearman, 1904, 1923, 1927). He postulated the hypothesis of a general intelligence or *g* factor making some contribution to success in diverse forms of cognitive activity. Subsequently, two contrasting postulates on cortical localization of intelligence were put forward. The first proposes that, processing of any task receives contribution from a large set of components or information-processing functions (Lashley, 1921, 1929; Satz, Strauss, & Whitaker, 1990; Thomson, 1951; Thurstone, 1938, 1940). Therefore, any two tasks are likely to share at least some components, giving rise to universal positive correlation. This hypothesis assumes that, general ability is diffusely represented on the whole cortex, and injury to any region of the brain produces an intellectual decrement. Conversely, the second, so-called hierarchic hypothesis postulates that, in the course of evolution some area of the brain has gained a dominant role in sustaining general intelligence (Basso, De Renzi, Faglioni, Scotti, & Spinnler, 1973).

Snow, Kyllonen, and Marshalek (1984) have classified intelligence tests by task complexity, into tests at the center and tests at the periphery. Psychometric tests including RPM (Raven, 1938) and other complex reasoning tests were classified as tests at the center, while simpler tests were placed at the periphery. Applying this construct, irrespective of the views held by both hypotheses, the centrality of the RPM emerges in either case.

Furthermore, it has been suggested that RPM is a good test of intelligence, and should account for a great deal of the reasoning in other tests (Carpenter, Just, & Shell, 1990). It has been suggested that the neural substrate for intelligence lies within prefrontal cortex (Prabhakaran, Smith, Desmond, Glover, & Gabrieli, 1997), and

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post-rolandic structures (Basso et al., 1973). Recently, positron emission tomography studies have shown selective recruitment of lateral prefrontal cortex in one or both hemispheres (Duncan et al., 2000). Studies of cerebral lateralization of intelligence may implicate one hemisphere, or both, if general abilities were diffusely represented.

Cerebral lateralization could be studied using TCD (Bulla-Hellweg, Vollmer, Götzen, Skreczek, & Hartje, 1996; Cupini et al., 1996; Droste, Harders, & Rastogi, 1989; Evers, Dannert, Rodding, Rotter, & Ringelstein, 1999; Hartje, Ringelstein, Kistinger, Fabianek, & Willmes, 1994; Kelley et al., 1992; Markus & Boland, 1992; Njemanze, 1991, 1996, 2002, 2004; Njemanze, Gomez, & Horenstein, 1992; Rihs, Gutbrod, Steiger, Sturzenegger, & Mattle, 1995; Silvestrini, Troisi, Matteis, Razzano, & Caltagirone, 1994; Varnadore, Roberts, & McKinney, 1997; Vingerhoets & Stroobant, 1999). Studies with TCD have been cross-validated by functional MRI (Schmidt et al., 1999), and reproducibility assessed (Knecht et al., 1998).

The purpose of the present study is to evaluate cerebral lateralization during RPM tasks in females and males. It is postulated that general intelligence is associated with neural systems represented in one hemisphere that are accessible to a variety of cognitive processes. Consequently, unilateral representation of general intelligence will cause MBFV changes in ipsilateral MCA during performance of intelligence tasks. More specifically, the present study evaluates MBFV changes in both MCAs during performance of RPM tasks in both female and male subjects.

2. Materials and methods

2.1. Subjects

The studied group included 24 normal volunteers, 15 female and 9 male. Mean age was 25.08 ± 3.16 years (range 21–33); females (25.47 ± 3.5 years) did not differ from males (24.44 ± 2.5 years). All were right-handed as determined using the Edinburgh handedness inventory (mean laterality quotient was 100) (Oldfield, 1971). Subjects had no history of neurological or cardiovascular or respiratory diseases. None was under medication, including contraceptive pills for females or recreational drugs. All refrained from ingesting caffeine at least 24 h prior to the study. The years of schooling ranged from 16 to 18. All subjects signed informed consent for the study. The Institutional Ethical Committee approved the study protocol.

2.2. Normal resting baseline measurements

Baseline data acquisition were made with subject in supine horizontal position with head inclined up at 30°. The eyes were fixated on a cube target, projected onto a screen, placed 80 cm (from the nasal ridge) in front of the subject. The ears were partially closed with earplugs that also provided the base of the probe holder. All environmental noise including sound from the TCD instrument was excluded, and environmental luminance was kept constant for all participants. Measurements comprising a 60 s continuous train of velocity waveform envelopes were recorded with subject mute, still, and attention focused on the cube with no mental or manual task to perform.

2.3. Raven's progressive matrices test

Eight successive black and white slides of RPM tasks were arranged in increasing levels of difficulty and sequentially projected on a screen. Subjects were required to determine which of the 6–8 options best completes the matrix, so that the inter-relational rules among the elements between the row and columns were met. No verbal answers were required, instead subjects were asked to indicate their choice of option by slightly raising the corresponding finger during the inter-stimulus interval. The fingers were numbered sequentially from 1 to 8, starting with the right thumb as the first option to the left middle finger as option eight. An observer recorded the option signed by the subject during the 2 s inter-stimulus interval, also used for task slide transition. All responses were transformed into *Wrong* or *Correct* ANSWER. Measurements comprising a 60 s continuous train of velocity waveform envelopes were recorded during each task with subject mute, still and attention focused on the task.

2.4. Transcranial Doppler measurement

Transcranial Doppler scanning was performed by a method similar to that previously described elsewhere (Njemanze, 1991, 1996, 2002), using a bilateral simultaneous TCD instrument (Multi-Dop T, DWL, Sipplingen, Germany). MBFV in both MCAs was sampled in supine horizontal position using two 2 MHz transducers, with probes fixated on both temples using a probe holder—LAM-Rack (DWL, Sipplingen, Germany). The Doppler signals and a continuous train of flow velocity envelops were obtained at a depth of 50 mm from the probe surface with the same gain and power settings for each subject. MBFV was recorded and averaged in 10 s segments for each condition. Subjects were instructed to remain mute and motionless, and the probe-to-vessel angle remained constant throughout the data acquisition.

2.5. Other monitoring tests

Electrocardiographic monitoring and respiratory activity were recorded during experimental runs for control of any effects. Self-perceived anxiety levels by stan-