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Research report

Functional cerebral lateralization and dual-task efficiency—Testing the function of human brain lateralization using fTCD

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ABSTRACT

It has been hypothesized that functional cerebral lateralization enhances cognitive performance. Evidence was found in birds and fish. Our study aimed to test this hypothesis by analyzing the relationship between cerebral lateralization and both single-task performance and dual-task efficiency in humans. We combined a dynamic Landmark task which is assumed to be primarily processed in the right hemisphere and a frequently used word generation task which is assumed to be primarily processed in the left hemisphere. For each task individual strength and direction of hemispheric lateralization was assessed using functional transcranial Doppler sonography (fTCD). For each subject (15 women, 11 men), performance was measured in the two single-tasks and in the dual-task condition.

Performance was not related to strength or direction of lateralization in single-tasks. With regard to dual-task efficiency, we found the expected advantage of having a typical lateralization pattern. Moreover, the results showed a slight negative, rather than a positive, relationship between strength of lateralization and dual-task efficiency. Further analysis showed that this negative relationship may only be present in subjects showing non-significant lateralization for one or both tasks. Therefore, the hypothesis that cerebral lateralization enhances human cognitive performance is too general: having two functions significantly lateralized to different hemispheres enhances dual-task efficiency, in this group strength of lateralized does not matter. However, if one or both functions are not significantly lateralized overall performance is worse and in this group, performance is negatively related to increased strength of lateralization.

1. Introduction

Brain lateralization refers to the intriguing phenomenon that the two hemispheres differ in their structure and in their functional output [5]. Most people show the typical lateralization pattern in which the left hemisphere is more involved in language tasks, while the right hemisphere is more involved in visuospatial tasks. Until recently such brain lateralization was thought to be a unique property of humans. However, recent research in biology has revealed functional lateralization in all five classes of vertebrates [38,42,43] and even in some invertebrates [1,6,29]. It is therefore likely that lateralization emerged early in evolution [38] and its prevalence indicates a major advantage to the individual [17]. Such an advantage might become evident as enhanced performance in single- and dual-tasks. In this study we will examine the relationship between cerebral lateralization and both single-task performance and dual-task performance.

With regard to single-tasks it has indeed been shown that stronger lateralization is related to better performance in animals, e.g. enhanced visual discrimination in the pigeon [17] and more effective termite fishing in wild chimpanzees [30]. A positive relationship between stronger lateralization and single-task performance has also been shown in human research, e.g. better face recognition abilities [2] and increased cognitive abilities [31]. However, both in animal and in human research the results on single-task performance seem to be task dependent [4,19,36]. In humans for example, Boles et al. [4] reported that a higher degree of asymmetry in performance (measured using visual half field or auditory dichotic presentation) was related to better performance in a spatial positioning task and in auditory linguistic tasks (dichotic listening procedures), whereas in other (e.g. visual lexical) tasks a higher degree of asymmetry in performance was related to a decrease in performance. Thus, results with regard to lateralization and single-task performance are inconclusive.

With regard to dual-task performance it has been suggested that lateralization enhances performance by enabling parallel processing [38]. This parallel processing hypothesis has been tested in animal studies, which have shown that brain later-

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alization may indeed be beneficial for dual-task performance: e.g. enhanced predator detection during recognition of cryptic food in chickens [11,37] and fish [7]. Dual-task performance in humans has been studied intensively from cognitive psychological (e.g. [15,33,41,47,50–52]) and neuropsychological perspectives (e.g. [23,24]). Here, an important measure is dual-task interference, i.e. decrease in performance in the dual-task compared to the single-tasks. Broadly speaking, such performance decrement reflects the degree to which the two tasks compete for the same limited cognitive resources. This leads to the prediction that performance decrement will be less when two tasks only weakly compete for the same cognitive resources. When the two hemispheres are regarded as two separate cognitive resources (e.g. [15,51]), the prediction is that dual-task interference will increase when both tasks are performed by the same hemisphere, and that there should be less interference when different hemispheres are involved. Thus, lateralization could enable more efficient dual-task performance, a hypothesis similar to the parallel processing hypothesis.

Although there have been various studies of hemispheric involvement in dual-task interference, most studies did not actually measure the individual brain lateralization patterns. Rather, most studies included only right-handers (on the assumption that right-handers have the typical lateralization pattern of language in the left hemisphere and visuospatial functions in the right hemisphere) and manipulated hemispheric workload by varying the nature of the tasks, visual field and response hand (see for example [34] for an overview). Recently, Hirnstein et al. [18] presented the first study on the relationship between degree of individual lateralization at the behavioural level and dual-task performance. They used two visual half-field tasks: a face-discrimination (right hemisphere) and a lexical-discrimination (left hemisphere) task. In the face-discrimination task subjects indicated as quickly and accurately as possible whether the stimulus represented a normal face or a non-face. Analogously, in the lexical decision task subjects had to discriminate between visually presented words and non-words. For each single-task, an absolute individual performance asymmetry index was calculated for both accuracy and response times in the right compared to the left visual field to discriminate between strongly and weakly lateralized subjects. Subsequently, a dual-task was administered in which both tasks were presented simultaneously; one in the left visual field (response with the left hand) and one in right visual field (response with the right hand). Subjects had to respond as quickly and as accurately as possible to both tasks at the same time. Based on results from animal studies that aimed to test the parallel processing hypothesis, they predicted that more lateralized subjects would outperform less lateralized ones. Interestingly, they found the opposite. Less lateralized subjects responded faster and more accurately than more lateralized subjects. Làdavas and Umiltà [28] reported a similar relationship for single-task discrimination of facial expressions and suggested that this could be the result of a better cooperation between the hemispheres. Accordingly, Hirnstein et al. [18] explained their results by proposing that less lateralized participants also benefit from a better cooperation between hemispheres in dual-task situations.

Our study differs from the study of Hirnstein et al. [18] in several ways. Importantly, as mentioned by Hirnstein et al. [18], their design did not account for individual variations in single-task performance, leaving open the possibility that the better performance of the less lateralized participants in the dual-task resulted from better performance in the single-task conditions. Instead of analyzing sole dual-task performance, we studied dual-task efficiency, i.e. the individual difference between single- and dual-task performances, thereby accounting for individual differences in single-task performance. Whereas Hirnstein et al. [18] based their laterality measures on task performance, we used functional transcranial Doppler ultrasonography (fTCD) to provide a physiological measure of brain lateralization independent of performance. FTCD measures task-related changes in cerebral blood flow velocity (CBFV) in the medial cerebral arteries (MCA's). Increased CBFV in one of the MCA's indicates higher neural activity in the corresponding hemisphere. The averaged hemispheric perfusion difference is calculated as a robust index of lateralization [12]. FTCD has recently become a well established non-invasive method to measure individual functional cerebral lateralization [10,27,40].

The fTCD method assesses two aspects of lateralization that may be important, its strength and its direction. There is some evidence that it is strength of lateralization rather than direction that is important for performance [4,31]. However, the fact that both non-humans [42] and humans (e.g. [13,27]) show lateralized behaviour at the population level and that it is often postulated that there is a link between atypical cerebral lateralization and disorders in humans (e.g. [20,22,48]) and decreased performance in animals [17] suggest that an advantage of having a lateralized brain might not only depend on degree of lateralization, but also on direction. The present study therefore takes both degree and directionality of cerebral lateralization into consideration.

To summarize, the aim of the present study is to investigate the relationship between cerebral lateralization and both single- and dual-task efficiency. Individual degree and direction of lateralization were measured with fTCD during a single word generation (linguistic) task and a single visual dynamic Landmark (visuospatial) task. The latter task is an adapted version of the well known Landmark task, that enables both fTCD and performance measurement. Single-task performance and dual-task performance were assessed for each individual. From a Darwinian function perspective the prediction is that performance will increase with increasing strength of cerebral lateralization. Next, based on the parallel processing hypothesis, we predict that a higher degree of cerebral lateralization will be related to increased dual-task efficiency. Additionally, both the high proportion of typically lateralized subjects in the population and the higher proportion of atypically lateralized subjects among people with disorders suggest an advantage of being typically lateralized. Therefore, we predict that performance will be increased in subjects who show the typical lateralization pattern of language left and visuospatial functions right compared to subjects who do not show this typical pattern.

2. Methods

2.1. Subjects

Twenty-six healthy normal volunteers participated in the study (15 women and 11 men; mean (SD) age 21.0 (1.98) years). All were Dutch 1st or 2nd year psychology students who received research credits for participation. They had normal or corrected-to-normal vision. They all wrote with their right hand and were right-handed as measured with a 10-item handedness questionnaire (adapted from [45], hand preference index: mean [min–max] = .90 [.60–1.00]). Subjects refrained from drinking alcohol and smoking at least 12 h before the experiment. They were not diagnosed with epilepsy or dyslexia and did not use any medication other than contraceptive pills. In addition, they had no (history of) neurological disorder, head trauma, concussion, meningitis or encephalitis, nor any other brain injury. All subjects gave written informed consent. The study was approved by the Ethics Committee of the Psychology Department of the University of Groningen.

2.2. Apparatus

A Doppler ultrasonography device (DWL Doppler Box, Compumedics Germany GmbH) was used. CBFV was monitored continuously and simultaneously in the left and right middle cerebral artery (MCA) by two 2-Mhz transducer probes. The two probes were fixed bilaterally at the temporal skull windows and oriented to obtain optimal signals. Details of this technique and the correct identification of the MCA have been described elsewhere [35]. Insonation depth ranged from 43 to 62 mm (mean (SD): 53 (5.6)). Hemispheric dominance and task performance were measured during a word generation task and a dynamic Landmark task (see below). In the dynamic Landmark task participants responded by using a joystick (Logitech ATTACK 3). During all tasks subjects were seated in a quiet room in front of a 22 in. computer screen at approximately 84 cm distance. The joystick was placed in front