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Anomaly detection in the right hemisphere: The influence of visuospatial factors

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Abstract

Previous research with both brain-damaged and neurologically intact populations has demonstrated that the right cerebral hemisphere (RH) is superior to the left cerebral hemisphere (LH) at detecting anomalies (or incongruities) in objects (Ramachandran, 1995; Smith, Tays, Dixon, & Bulman-Fleming, 2002). The current research assesses whether the RH advantage for anomaly detection is due to the RH superiority for visuospatial skills or is a distinct cognitive process. Sixty undergraduate participants completed tasks assessing anomaly detection, mental rotation, and global and local perceptual abilities. The results demonstrate that anomaly detection is negatively correlated with mental rotation. These findings suggest that anomaly detection is not simply a function of visuospatial skills.

1. Introduction

Ramachandran (1995) has suggested that the right cerebral hemisphere (RH) acts as an anomaly detector that analyzes information (e.g., visual displays and information pertaining to body image) for the presence of features that render this information logically or structurally impossible. Ramachandran first proposed the "right-hemisphere anomaly detector" to account for behaviours exhibited by anosognosics and split-brain patients. Patients with left hemiplegia who had damage to the right parietal lobe did not consciously admit to being paralyzed. Instead, they claimed to be fully mobile. Patients would posit statements that would superficially account for the incongruity between their claims of being healthy and their inability to move the left side of their bodies (e.g., "I'm just really tired"). In contrast, patients with right hemiplegia who had damage to the left parietal lobe were fully aware of their deficits. This hemispheric difference suggested a unique role for the RH in detecting the presence of anomalies. Ramachandran (1995) tested this hypothesis using a split-brain patient, LB. LB was shown Penrose's impossible triangle (a visual anomaly) in one visual field and then the other. This patient only noticed the anomaly when the triangle was presented to the left visual field (or RH).

Previous research in our lab (Smith, Tays, Dixon, & Bulman-Fleming, 2002) demonstrated that the RH advantage in detecting anomalies that was found in patient-based studies can be generalized to neurologically intact individuals. Two types of stimuli were presented to healthy participants. One set consisted of familiar objects taken from the Snodgrass and Vanderwart (1980) set of line drawings. The second set consisted of unfamiliar objects taken from the Williams and Tarr (1997) set of irregular polygons (see Fig. 1). Participants were shown possible and impossible versions of all stimuli. Impossible familiar objects consisted of line drawings that were altered to make the object functionally impossible. Impossible unfamiliar objects consisted of polygons that could not exist in real space. The results of this study provided tentative support for Ramachandran's (1995) hypothesis that the RH is specialized to detect anomalies. Specifically, in male participants, the RH was more accurate than the left hemisphere (LH) at detecting anomalous objects. There were no significant hemispheric differences for the detection of possible stimuli. This pattern was found for

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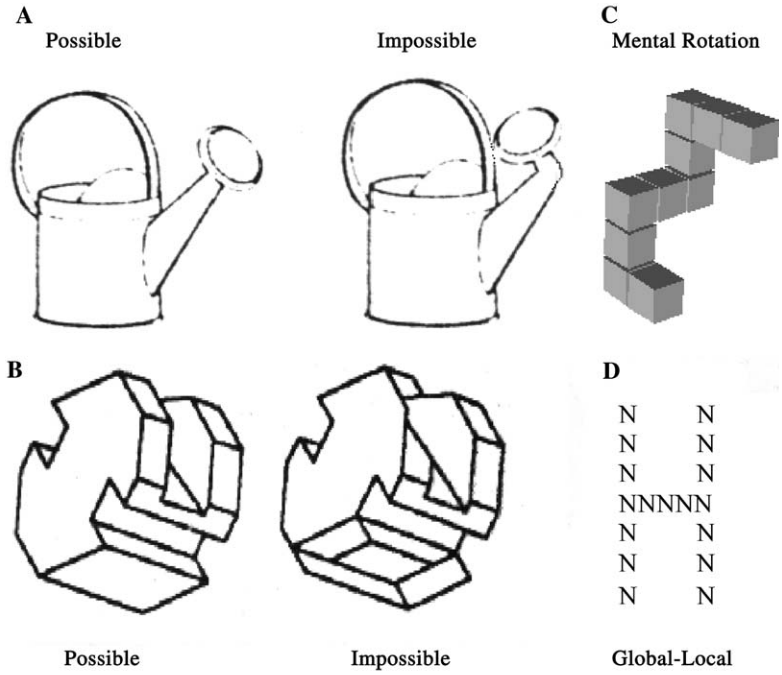

Fig. 1. Displayed in (A) are possible and impossible objects based on Snodgrass and Vanderwart (1980). These are *familiar objects*. In (B) are possible and impossible objects based on Williams and Tarr (1997). These are *unfamiliar objects.* In (C) is a sample of the stimuli used in the mental-rotation task. In (D) is a sample of stimuli used in the global-vs.-local-perception task.

both familiar and unfamiliar stimuli. There were no hemispheric differences for female participants, a pattern likely due to the fact that females are not as strongly lateralized as males (Bryden, 1982).

The current research is designed to extend our previous finding in two ways. First, we sought to replicate the original anomaly detection findings using a larger sample size. In our original paper (Smith et al., 2002), male ($N = 12$) but not female ($N = 14$) participants showed the predicted effect. The current research used 60 male participants in order to replicate our earlier findings. Second, we sought to rule out the possibility that the RH advantage for anomaly detection was a result of the RH's general superiority for visuospatial processing. If this was the case, then participants who performed well on the anomaly detection task should perform well on other visuospatial tasks. This result would cast doubt on the conclusion that the RH contains a specific cognitive module designed for detecting anomalies. However, if anomaly detection capabilities and visuospatial skills are not correlated, then we can conclude that the RH superiority for anomaly detection is due to its superior ability to check information for incongruities (cf. Ramachandran, 1995).

In order to ascertain the relation between anomaly detection and visuospatial skills, we had participants in the current study perform three tasks: (1) anomaly detection, (2) mental rotation, and (3) global-vs.-local perception. The anomaly detection task was identical to that used in our previous research. The two tasks that we have labeled "visuospatial" each assess different components of visual perception. Global perception involves the analysis of the overall structure of the stimulus, whereas mental rotation involves the analysis of transformations to the spatial characteristics of the stimulus. Critically, both tasks are typically viewed as right-hemisphere tasks (Hellige, 1995). Therefore, if anomaly detection is simply a result of a RH visuospatial superiority, performance on mental rotation and global perception should correlate highly with anomaly detection performance. If, however, anomaly detection is a distinct cognitive process, then the results on this task should not be related to the results of the visuospatial tests.

2. Methods

2.1. Participants

Sixty male students participated in this study in exchange for monetary remuneration or for course credit in an introductory psychology class. All participants were right-handed (as confirmed by the Waterloo Handedness Questionnaire) and had normal or corrected-to-normal vision.

2.2. Stimuli and apparatus

The stimuli used in the anomaly detection task (see Fig. 1) were identical to the familiar and unfamiliar objects used in our earlier studies (Smith et al., 2002). The possible and impossible familiar objects were derived from a standardized set of line drawings (Snodgrass & Vanderwart, 1980). Forty line drawings of man-made objects served as the possible familiar objects. To create forty familiar, "impossible objects," parts of these line drawings were altered using a graphics program. The changes rendered the objects functionally unusable and thus anomalous (e.g., a chair with a leg missing; a watering can with the spout pointing backwards).

The possible and impossible unfamiliar objects were taken from a standardized set of irregular polygons constructed by Williams and Tarr (1997). Forty of the items were constructed such that they could exist in real space (i.e., they were *possible* objects). The other forty items contained an alteration of a structural feature such that the resulting irregular polygons could not exist in real space (i.e., they were *impossible* objects). Participants were shown forty possible and forty impossible objects from both the familiar and unfamiliar stimulus sets, thus resulting in 160 experimental trials. On each trial, an object was presented to the right or to the left of the centre of the computer screen. The side of presentation and the type of object presented (possible or impossible) were each randomized with the constraint that all participants received an equal number of possible and impossible objects in both the left and right visual fields.

These stimuli were presented on a 12″ colour monitor connected to a MacIntosh 650 Centris computer. The stimuli were presented in a 9×9 cm area, the centre of which was 5.4 cm from fixation. The black line drawings were presented on a white background and viewed from a distance of 35 cm. At the beginning of each trial, participants were instructed to focus on a central fixation cross in order to ensure that their eye movements did not serve as a confound; head movements were controlled by having participants use a chin-rest. Participants indicated whether objects were possible or impossible via a keyboard response. The hand of response was counterbalanced such that the left and right index fingers were each used to respond to both types of items (possible and impossible).

The stimuli used in the mental-rotation task were digital photographs of 3-dimensional polygons. Each polygon consisted of 10 white cubes aligned to form a unique shape (see Fig. 1). The shapes measured approximately 50 mm $\times$ 35 mm. On each trial, a target item was presented 50 mm below a central fixation cross for 1 s. Following this display, a rotated version of the target item and a distractor item were presented 30 mm to the left and right of the central fixation cross (rotated targets and distractors appeared either on the left or right of fixation equally often). Participants completed five practice trials followed by 42 test trials; thus, 126 polygons were created. These items were displayed on a 21″ monitor connected to a PowerMac 7100/66w processor.

The stimuli used in the global-vs.-local-perception task were hierarchical letters (cf. Navon, 1977). These stimuli consisted of smaller letters (the local level) presented together in a pattern that constructed larger letters (the global level). For example, participants could see a large "N" made up of smaller "H's". The smaller letters were 4-mm tall $\times$ 2-mm high and the larger letters were 45-mm tall $\times$ 42-mm wide. On each trial, an "E" or an "H" appeared as either the global or local letter. Participants were instructed to respond as to which of the two letters appeared via a keyboard response.

2.3. Procedure

Participants first completed the Waterloo Handedness Questionnaire and the Waterloo Footedness Questionnaire (Elias, Bryden, & Bulman-Fleming, 1998). The participants then completed the three computer tasks, the order of which was counterbalanced across participants. Participants were instructed to complete all trials as quickly and as accurately as possible.

In the anomaly detection task, each participant completed four blocks of trials consisting of eight practice trials and 40 test trials. Each trial began with a fixation cross that was displayed for 500 ms followed by a possible or impossible object presented to the left or to the right of fixation for 150 ms. Participants indicated via a keypress whether a possible or impossible object was presented. After each trial, there was a 1000 ms delay before the next trial began.

In the mental-rotation task, each participant completed five practice trials and 42 test trials. Each trial began with a fixation cross displayed for 500 ms followed by a target polygon that was presented for 1000 ms, 50 mm below fixation. Following this presentation, two objects—a rotated version of the target and a distractor—were presented for 150 ms to the left and right of fixation. Participants indicated via a keypress whether the rotated target was on the left or right of fixation. After each trial, there was a 1000 ms delay before the next trial began.

In the global-vs.-local-perception task, each participant completed 200 trials. Each trial began with a fixation cross displayed for 500 ms followed by a centrally displayed hierarchical letter. Letters remained on screen until participants indicated (via a keypress) whether the letter presented was an E or an H. After each trial, there was a 1000 ms delay before the next trial began.

3. Results and discussion

Mean accuracy and response times were calculated for each participant on all three tasks. Response times were analyzed for outliers using a trimming method that removed scores more than three standard deviations away from the individual participant's response-time means. The data from three participants were eliminated because of chance performance and extremely fast reaction times on all three tasks, thus leaving 57 participants in the final analyses.

A repeated-measures analysis of variance was conducted on response time and accuracy for the anomaly detection task. For the unfamiliar objects (the Williams and Tarr irregular polygons), there was no effect of reaction time ($F < 1$). However, the accuracy data replicated our previous results (see Fig. 2). There was a significant Hemisphere × Object Type (possible vs. impossible) interaction: $F(3, 56) = 6.591$, $p < .05$. Critically, the RH was significantly better than the LH at determining that an object was impossible: $t(56) = 2.67$, $p < .05$. In order to assess overall sensitivity of the two hemispheres, A′ scores were calculated for the accuracy data. These scores did not show a significant hemispheric asymmetry. However, as anomaly detection is proposed to be a distinct cognitive mechanism independent from the perception of possible items, the A′ result should not alter the interpretation of the data.

For the familiar objects (the Snodgrass and Vanderwart line drawings), there was a significant effect of reaction time: $F(3, 56) = 4.720$, $p < .05$ (see Fig. 3). Possible objects were responded to more quickly than impossible objects: $F(3, 56) = 7.424$, $p < .05$. Although there was no hemispheric asymmetry for reaction times to possible objects, there was a difference for impossible objects. Impossible objects presented to the RH were responded to more quickly than impossible objects presented to the LH: $t(56) = 2.754$, $p < .05$. Thus, the current findings replicate our previous study (Smith et al., 2002). Specifically, support for a RH anomaly detector was found in the accuracy data for unfamiliar objects and in the reaction-time data for anomalous familiar objects.

The means and reaction times for the mental-rotation task and the global-vs.-local-perception task were calculated for each participant. The mean accuracy of the mental-rotation task was 61.4% ($SD = 12.3\%$). The means of the global-vs.-local-perception task were unfortunately above 95% for all participants. Because of this ceiling effect, the global-vs.-local-perception task was excluded from further analysis.

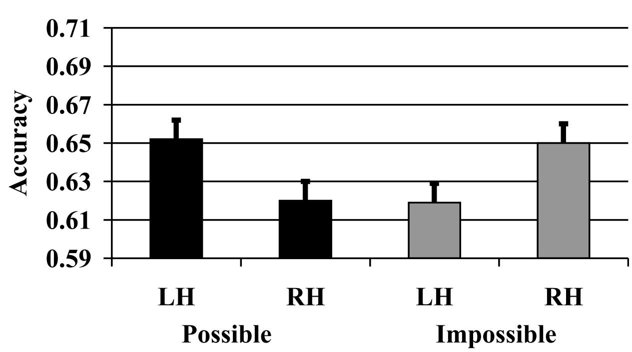

Fig. 2. A graphical representation of means for accuracy data found for anomaly detection in unfamiliar objects (the irregular polygons).

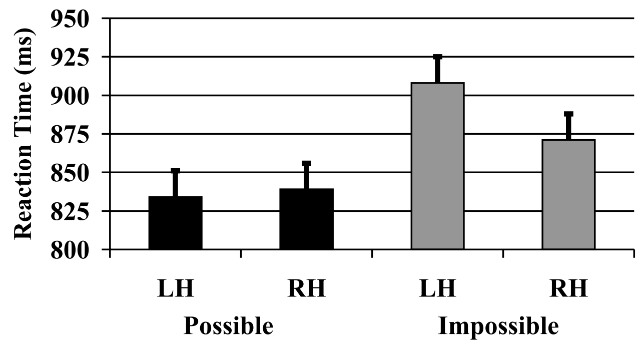

Fig. 3. A graphical representation of mean reaction times found for anomaly detection in familiar objects (the Snodgrass and Vanderwart line drawings).

In order to assess, whether anomaly detection capability was correlated with spatial skills, our strategy was to take the data from tasks in which there was putative evidence for a RH anomaly detector (accuracy data for detecting anomalous unfamiliar objects, and reaction time data for detecting anomalous familiar objects), and see if there were significant positive correlations with mental-rotation capabilities. Participants' mental-rotation accuracies were negatively correlated with their accuracy scores for detecting anomalies in unfamiliar objects (the irregular polygons): $r = -.281$, $p < .05$. Participants' reaction times on the mental-rotation task were not significantly related to their reaction times for detecting anomalies in the familiar objects (the line drawings of objects): $r = .046$, $p = .740$. Thus, we can conclude that the RH anomaly detector is *not* a result of RH superiority at general visuospatial skills.

The results of the current research have demonstrated that the RH advantage for anomaly detection is a reliable effect. For familiar objects, the RH was *faster* than the LH at detecting an anomaly. For unfamiliar objects, the RH was *more accurate* than the LH at detecting an anomaly. The current research has also demonstrated the RH advantage for anomaly detection is not simply a component of the general RH superiority for visuospatial skills such as mental rotation. Participants who were relatively poor at mental-rotation tasks showed a greater RH advantage for anomaly detection than participants who were better at mental rotation. This pattern of results suggests that different cognitive mechanisms are involved in mental rotation and anomaly detection, and lends tentative support for the idea that there is a cognitive module located in the right hemisphere devoted to detecting incongruities in the world around us.

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