

## Experience with a category alters hemispheric asymmetries for the detection of anomalies

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### Abstract

Previous research with both brain-damaged and neurologically intact individuals suggests that the right cerebral hemisphere (RH) is superior to the left cerebral hemisphere (LH) at detecting anomalies in objects. The current research assesses whether experience with a category is necessary for this RH advantage to emerge. Participants were taught the diagnostic criteria necessary to categorize two fictitious species of animals (“Dleebbs” and “Tazes”). After training, participants were given a test in which half of the items were congruent with the diagnostic rules and half of the items were incongruent. Participants were tested on two occasions—once after the initial training session and once after five training sessions. The results demonstrated that experience is required for the RH advantage for anomaly detection to occur. On the first test, reaction times were faster when items were presented to the LH. After 5 days of training, reaction times were faster when items were presented to the RH. This interaction could be due to the fact that participants reported analyzing the items in terms of a series of features during the initial test, but analyzed the items as a configural whole as experience with the category increased.

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Ramachandran (1995) has hypothesized that the two cerebral hemispheres differ in their ability to critically analyze sensory information. Based on work with anosognosic and split-brain patients, he has suggested that the left hemisphere (LH) serves as a “story-teller” that generates, and in some cases confabulates, narratives that explain the myriad of situations we encounter and stimuli we perceive in everyday life (see also Gazzaniga, 1998). In contrast, the right hemisphere (RH) acts as an “anomaly detector” that analyzes the LH’s narratives for information that would render its conclusions logically impossible. Ramachandran used this hemispheric dichotomy to explain why patients with anosognosia resulting from right parietal damage refuse to admit their hemiparesis and instead confabulate a story to explain their symptoms (e.g., “My arm can move, but I’m tired right now”). This di-

chotomy also explained the fact that a split-brain patient did not notice that an impossible figure (Penrose’s triangle) was in fact impossible when this stimulus was viewed with the LH; critically, this patient immediately detected the problem with the stimulus when viewing it with the RH. Both of these cases suggest that the RH is superior to the LH at determining whether information is anomalous or not.

In a series of studies, we have sought to extend this patient-based research in order to determine whether neurologically intact individuals show a hemispheric difference for the detection of anomalies in the visual domain. In an initial study (Smith, Tays, Dixon, & Bulman-Fleming, 2002), we used a divided-visual field technique to present possible and impossible objects to healthy participants. In one condition, anomalous objects were perturbations of familiar objects (adapted from the Snodgrass & Vanderwart, 1980 set of line drawings). The line drawings were presented either in their standard form or were altered so as to render them ‘impossible’ (e.g., a car with square wheels). In a second condition, participants viewed possible and impossible figures that were completely

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novel to participants. These unfamiliar stimuli were three-dimensional, irregular-polygons (see Schacter, Cooper, & Delaney, 1990; Uecker et al., 1997; Williams & Tarr, 1998). Some of these unfamiliar stimuli were structurally possible, whereas others contained an anomaly that rendered them structurally impossible. The results of our initial study demonstrated that for male, but not female participants, the RH was more accurate than the LH at detecting anomalies in both the familiar and the unfamiliar objects. This difference in accuracy suggests that the RH advantage was not simply due to the LH requiring more time to analyze the items, but instead reflected superior processing abilities for this task.

Our subsequent studies replicated this RH advantage and ruled out the possibility that our results were attributable to an overall RH advantage for visuospatial skills. Specifically, performance on mental rotation (Smith, Dixon, Tays, & Bulman-Fleming, 2004) and global versus local perception tasks (Smith, Schweizer, Dixon, & Bulman-Fleming, *in press*) did not predict participants' abilities to detect anomalies in objects. Thus, it appears that anomaly detection is not simply a function of these basic visuospatial skills.

Although the stimuli used in our previous studies allowed us to demonstrate that the RH is superior to the LH at detecting anomalies, these stimuli were problematic for two reasons. First, it was impossible to control the amount of experience participants had with the categories of stimuli. For instance, a participant who studied mathematics and engineering would have more experience with geometric figures than other participants. This increased experience might allow them to more efficiently analyze the stimuli to determine if they were possible or anomalous. Second, the diagnostic importance of the perturbations to the possible stimuli to render them anomalous differed across stimuli. For example, the anomalous version of the watering can had a spout bent upwards to make it functionally useless. If the handle of the watering can had been made square instead of round, the change would not have rendered the object as anomalous as did the alteration to the spout. It was important therefore to ensure that each perturbation was equally important or diagnostic. In the current study, we taught participants the diagnostic criteria for two novel sets of stimuli similar to the fictitious animals used by Allen and Brooks (1991). Using these sets of novel stimuli allowed us to control the amount of experience participants had with this category of stimuli and to control the diagnosticity of the altered features.

## 1. Method

### 1.1. Participants

Forty right-handed, male undergraduates from the University of Waterloo took part in this study. All participants had normal or corrected-to-normal vision and had no deficiencies in color vision. Participants were paid \$30Cdn in exchange for 5 days of testing lasting a total of 3.5 h. All par-

ticipants gave informed consent to participate in this study as per University of Waterloo Office of Research ethical guidelines.

### 1.2. Stimuli and apparatus

The stimuli consisted of two families of fictitious animals, each with a distinct set of characteristics (see Fig. 1). The diagnostic criteria of the "Taze" family of animals consisted of a round head, spotted body, and short legs. In contrast, the diagnostic criteria of the "Dleeb" family of animals consisted of a square head, striped body, and long legs. There were four different species within both the Taze and Dleeb families. These species reflected variations of non-diagnostic characteristics such as number of legs, size of the stripes or spots, and size of the head. The size and shape of the body was held constant across all species and families (35 mm in width and 25 mm in height). All of the stimuli were presented as black-and-white images during the training phases. During the two test phases (days 1 and 5), the bodies of the animals were colored pink, green, blue, purple, orange, yellow or red; each color was used equally often for Taze and Dleeb animals and did not serve as a diagnostic criterion (see Fig. 2). Dleeb and Tazes were presented in color to isolate the influence of anomalies within the presented characters from the influence of novelty. Presenting the creatures in different colors during the test allowed us to individuate the test stimuli; identical possible and identical anomalous stimuli were made to look slightly different. This differentiation was designed to force participants to analyze the diagnostic criteria for the stimuli rather than relying on an exact (i.e., black-and-white) memorial representation from the training stimuli. Participants were told that colored images that still met the diagnostic criteria for either the Taze or Dleeb families were to be judged as being possible animals. As well, during the anomaly detection test, participants viewed images of animals that possessed physical characteristics of both families (e.g., the round head and short legs of the Tazes combined with the striped body of Dleeb). It was explained to participants that these animals were to be judged as being anomalous, because they did not meet the diagnostic criteria for either Tazes or Dleeb.

All images were created using Adobe PhotoShop 6.0 (Adobe Systems, Incorporated, San Jose, CA). Stimuli were presented using PsyScope software (Cohen, MacWhinney, Flatt, & Provost, 1993) and were displayed on a Macintosh ColorSync 19 in. monitor connected to a Power Macintosh G3 computer. Participants viewed the stimuli from a distance of 30 cm; this distance was controlled by having participants use a chin rest attached to the computer table.

### 1.3. Procedure

On the first day of the experiment, participants completed the Waterloo Handedness Questionnaire (Elias, Bryden, & Bulman-Fleming, 1998) to confirm that they were right-handed. Following this, participants began the training

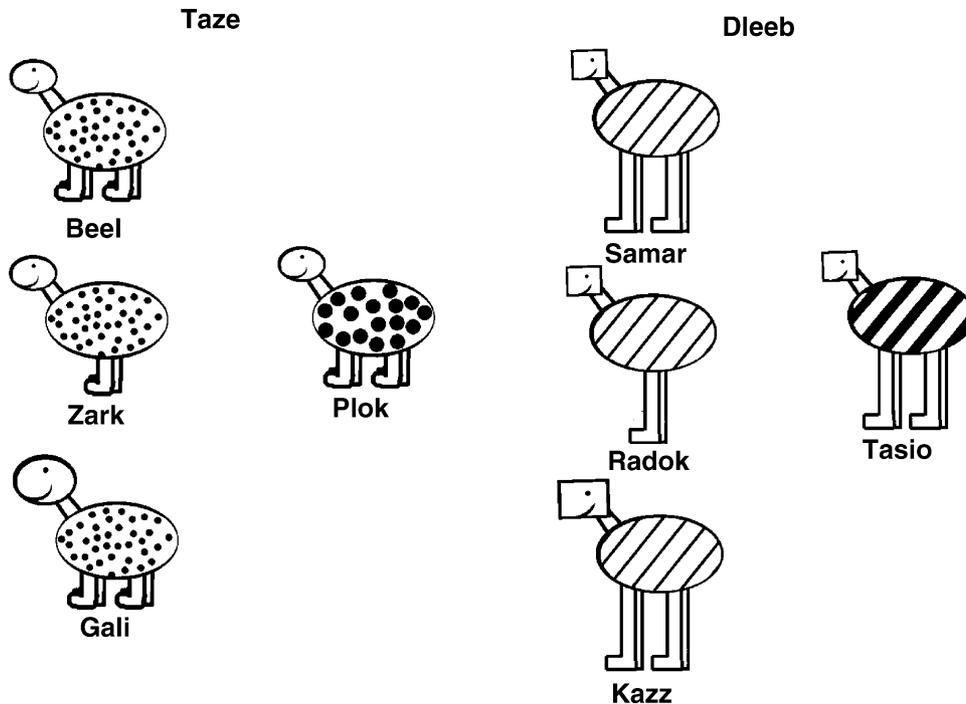


Fig. 1. Exemplars from the two families of fictitious animals used in the current study. The diagnostic criteria for being a member of the Taze family were having a round head, a spotted body, and short legs. The diagnostic criteria for being a member of the Dleeb family were having a square head, a striped body, and long legs. The individual species within each family varied along non-diagnostic dimensions such as head size, stripe or spot size, and number of legs.

sessions to teach them the diagnostic criteria for the two families of fictitious animals.

The training sessions completed by participants on each day of the experiment consisted of three separate phases. In the first training phase, participants viewed a display in which all eight animals (four species of animals from both families) were simultaneously visible to allow comparisons between items (see Fig. 1). Participants viewed this display for 2 min and were instructed to learn the stimulus features necessary for accurate family-level and species-level identification. Following this initial exposure, they completed blocks of eight learning trials for both species and family names. On each trial, a stimulus was centrally presented and remained

on the screen until the participants classified the image via a keyboard response. For the family-classification task, participants pressed the “g” or “h” keys to indicate whether the animal belonged to the Taze or Dleeb family. Family-key mapping was counterbalanced across training sessions and participants. For the species-classification task, participants responded by pressing one of the numbers from 1 to 8. In both learning tasks, participants were trained until they were able to complete six consecutive blocks of eight trials without making an error. If participants committed a naming error during this phase of the study, they were shown the original stimulus display of eight animals (Fig. 1) and were asked to review these stimuli for 1 min before continuing with this task. In the final phase of training, participants were shown a picture of one of the eight ‘animals’ and were asked to identify the stimulus as quickly and as accurately as possible. On each speeded-classification trial, a fixation cross was centrally presented for 500 ms. Subsequently, one of the eight animals was displayed and remained on the screen until participants responded with a key press. On 40 of the trials, participants indicated the family to which the stimulus belonged (i.e., “Taze” or “Dleeb”), and on 40 of the trials, they indicated the specific species shown. The order of the speeded trials (family versus species) was counterbalanced across training sessions and participants. The order of the stimuli presented within each block of 40 trials was randomized for each participant.

Participants completed an anomaly detection test on days 1 and 5 of this experiment. Each trial in this test began with a fixation cross-displayed on a white background for 500 ms.

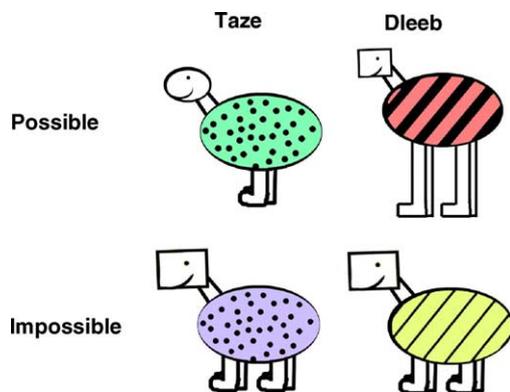


Fig. 2. Examples of possible and anomalous stimuli from the anomaly detection test.

After the fixation cross-disappeared, a possible or anomalous stimulus was presented for 150 ms to the left or right visual field. The stimuli were 50 mm × 35 mm in size and appeared 30 mm from fixation. After the test stimulus disappeared, the screen remained blank until participants indicated with a key press, whether the animal was possible or anomalous. Participants were instructed to respond as quickly and as accurately as possible. A new trial began 2000 ms after the previous response had been made. Participants completed 160 test trials: 40 possible and 40 anomalous trials for each visual field.

## 2. Results

Mean accuracy and response times were calculated for each participant within each experimental factor. The response times were analyzed for outliers by using a trimming method that excluded response times that were more than three standard deviations from the individual participant's response-time mean for each factor. The data from two participants were removed because these individuals did not follow the instructions. The data from the remaining 38 participants are depicted in Fig. 3.

The accuracy and response time data were entered into a 2 (test day: day 1 versus day 5) × 2 (hemisphere: right versus left) × 2 (stimulus type: possible versus anomalous) repeated-measures analysis of variance. There were no significant main effects or interactions in the accuracy data; participants accurately judged the stimuli to be possible or anomalous approximately 80% of the time. In contrast, the reaction-time data showed several interesting patterns. The three-way interaction between the variables of test day (days 1 and 5), hemisphere (LH and RH), and stimulus type (possible and anomalous) was significant:  $F(1, 37) = 4.37$ ,  $MSE = 8555.00$ ,  $p < 0.05$ . This interaction demonstrates that the RH was inferior to the LH at detecting anomalies on

day 1, but was superior to the LH on day 5. There was also a significant test day × hemisphere interaction:  $F(1, 37) = 9.72$ ,  $MSE = 12519.54$ ,  $p < 0.01$ . On day 1, the LH showed an overall superiority for processing both possible and anomalous stimuli; this LH advantage disappeared by day 5 and was replaced by an RH advantage for detecting anomalies. The test day × stimulus type interaction was not significant:  $F(1, 37) = 1.52$ ,  $MSE = 30234.66$ ,  $p = 0.22$ . There were significant main effects of test day, stimulus type, and a marginal effect of hemisphere. Reaction times decreased from days 1 to 5;  $F(1, 37) = 5.00$ ,  $MSE = 1542166.85$ ,  $p < 0.05$ . The main effect of stimulus type was also significant; participants found it easier to classify an item as being possible than anomalous:  $F(1, 37) = 4.55$ ,  $MSE = 22596.15$ ,  $p < 0.05$ . This pattern of data is consistent with our previous research (e.g., Smith et al., 2004). Finally, the main effect of Hemisphere was marginally significant:  $F(1, 37) = 3.37$ ,  $MSE = 44609.33$ ,  $p = 0.074$ , which is not surprising, because the relative superiority of the hemispheres changed across testing sessions.

Planned comparisons revealed that there was an LH advantage for classification of anomalous figures on day 1:  $t(37) = 2.90$ ,  $p < 0.01$  (see Fig. 3 (left)), testing on day 1 also revealed a marginally significant LH advantage for the analysis of possible figures:  $t(37) = 1.98$ ,  $p = 0.055$ . Thus, when participants have little knowledge of a category, the stimuli are more efficiently analyzed by the LH than by the RH. In contrast, there was an RH advantage for detecting anomalies once participants became more experienced with the stimulus categories (day 5):  $t(37) = 3.54$ ,  $p < 0.01$ . This result is consistent with the hypothesis that a RH advantage will emerge as experience with a category increases. There was no hemispheric difference for the perception of possible figures on day 5:  $t < 1$ . The fact that possible figures were classified at approximately the same speed and accuracy by both hemispheres, whereas the RH was more efficient at detecting anomalous figures suggests, that the hemispheric advantage

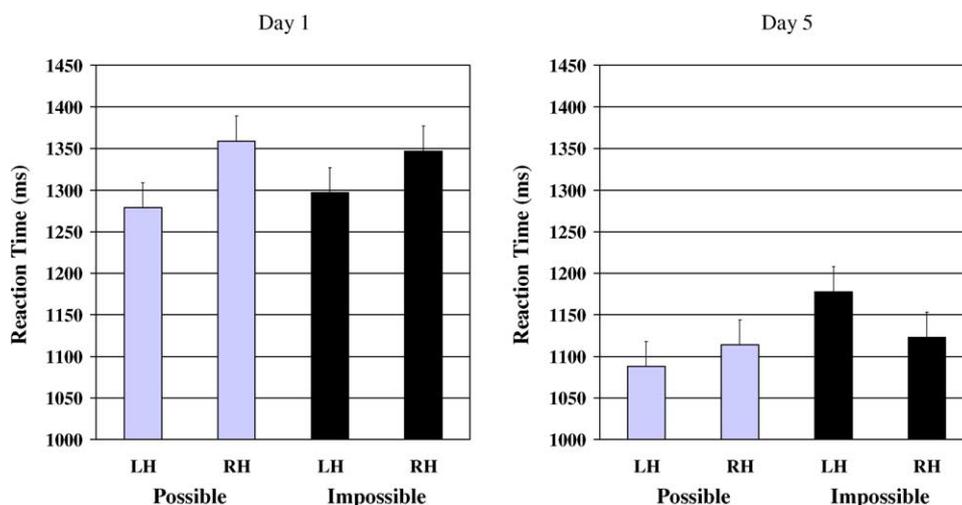


Fig. 3. Reaction times for the anomaly detection task performed on day 1 (left) and day 5 (right) of this experiment. Error bars represent standard errors of the mean.

was related to anomaly detection rather than being a more general categorization advantage. Finally, an analysis of variance was performed to determine whether specific anomalies (head shape, spots versus stripes or leg length) were easier to detect than others. The response times did not differ ( $F < 1$ ), suggesting that participants recognized that all three characteristics were equally important for classification.

### 3. Discussion

The current study provided two important extensions to our previous investigations of the right-hemisphere advantage for anomaly detection. First, using carefully controlled artificial categories allowed us to ensure that any parts of the animals that were changed to render the stimuli anomalous were equally important across all stimuli. The leg length, head shape, and body marking (striped versus spotted) were all equally diagnostic criteria for classifying the animals as Tazes or Dleebes. This degree of control was not possible in our earlier studies with common objects. Second, teaching participants to categorize two fictitious families of animals allowed us to control the amount of experience participants had with the categories. Each participant entered the experiment with no knowledge of the stimulus categories and saw the stimuli a similar number of times over the course of 5 days of training. Therefore, any individual differences in this study would not be a result of different levels of exposure to the objects being analyzed. Thus, we ensured that the features that made an animal anomalous were diagnostic features, and can conclude that experience mediates the hemispheric asymmetries for the detection of anomalies.

These results suggest that some experience with a category is required for the RH anomaly detection advantage to emerge. The amount of experience participants had with our stimulus categories was not designed to make them true ‘experts’, in the technical sense of the word (see Gauthier, Williams, Tarr, & Tanaka, 1998). Rather, the aim was for their experience level to be comparable to the degree of expertise or experience that participants had with the categories used in our previous work (Smith et al., 2002, 2004). Participants in these studies would have had considerable experience with the common objects (e.g., an ironing board, a wine bottle), but they were very unlikely to be true experts with these categories. Similarly, participants would have viewed irregular-shapes in math and art classes during their education, but were not likely to be irregular-polygon experts. Therefore, the fact that the RH advantage for anomaly detection was detected after participants gained experience with the categories of stimuli suggests that experience, but not expertise, was a critical factor in our previous work.

An important question for future research involves the mechanism underlying this RH advantage for detecting anomalies. Post-study interviews with the participants indicated that they had changed their analytical strategy between days 1 and 5. During the first test, participants claimed to have

analyzed the items on a feature-by-feature basis, whereas they engaged in more holistic or configural analyses as they became more experienced with the categories (see Rhodes, 1993). The analytical strategies of participants will be more formally assessed in future studies.

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