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Semantic, perceptual and number space: Relations between category width and spatial processing

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Abstract

Coarse semantic encoding and broad categorization behavior are the hallmarks of the right cerebral hemisphere's contribution to language processing. We correlated 40 healthy subjects' breadth of categorization as assessed with Pettigrew's category width scale with lateral asymmetries in perceptual and representational space. Specifically, we hypothesized broader category width to be associated with larger leftward spatial biases. For the 20 men, but not the 20 women, this hypothesis was confirmed both in a lateralized tachistoscopic task with chimeric faces and a random digit generation task; the higher a male participant's score on category width, the more pronounced were his left-visual field bias in the judgement of chimeric faces and his small-number preference in digit generation ("small" is to the left of "large" in number space). Subjects' category width was unrelated to lateral displacements in a blindfolded tactile-motor rod centering task. These findings indicate that visual-spatial functions of the right hemisphere should not be considered independent of the same hemisphere's contribution to language. Linguistic and spatial cognition may be more tightly interwoven than is currently assumed.

Keywords: Categorization behavior; Semantic processing; Functional hemispheric differences; Number space; Spatial attention; Pseudoneglect

In a largely forgotten approach, human subjects' categorization behavior was described as an important personality dimension. Almost half a century ago, Pettigrew noted the inclination of people to consistently categorize things within "narrow" or "broad" ranges [30]. He introduced an instrument to quantify individuals' breadth of categorization, the scale of "category width" (CW). This 20-item scale provides subjects with a series of average values of certain measurements and requires them to estimate (1) the lowest and (2) the highest measurement contributing to the respective average. One item thus asks for estimates of the flying speed of the fastest vs. the slowest birds:

> Ornithologists tell us that the best guess of the average speed of birds in flight would be about 17 m.p.h. What do you think:
> a. is the speed in flight of the fastest bird . . .
> 25 m.p.h. 105 m.p.h. 73 m.p.h. 34 m.p.h.
> b. is the speed in flight of the slowest bird . . .
> 10 m.p.h. 2 m.p.h. 12 m.p.h. 5 m.p.h.
> As "narrow" categorizers Pettigrew classified those subjects whose estimates for the lowest and highest values were close to one another in magnitude, as "broad" categorizers those whose estimates were numerically far apart.

From today's perspective, individual preferences in the width of categorization are considered a consequence of individual preferences for the width of associations and, as such, a function of the semantic system. In terms of semantic network theories, categories are represented as nodes, and are interconnected by a network of links along which activation proceeds automatically. It is conceivable that the width of categorization is critically dependent on the ease with which spreading activation travels within such networks. Both behavioral and neuroimaging studies have shown that processing of narrow, or close, semantic distances is primarily under control of the left cerebral hemisphere (LH), while broad, indirect or remote, semantic relationships are preferably processed by a less focused right hemisphere (RH) semantic system [2,21,27,33]. In fact, the early literature on

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neuropsychological correlates of individuals' breadth of categorization described an association between low CW scores (i.e., narrow categorization) and LH processing and between high CW scores (i.e., broad categorization) with RH processing [17,18]. In one study, narrow and broad categorizers recalled a comparable number of words presented to the right ear/LH in a dichotic listening paradigm, but the latter recalled more left ear/RH stimuli compared to the former [18]. This result was interpreted as meaning that "in comparison with narrow categorisers, there is greater right hemispheric involvement in processing in the case of broad categorisers" ([18], p. 538).

The purpose of the present experiment was to relate healthy subjects' breadth of categorization to their performances in spatial attention tasks with a firmly established cerebral hemispheric contribution. Conceiving of broad categorization behavior as mediated by the RH semantic system, we specifically predicted a positive correlation of scores on the CW scale with attentional biases toward the left side of space in (1) a divided visual field task with chimeric stimuli [1,7], (2) a tactile rod centering task [14], and (3) a random digit generation paradigm. This latter task, the *Mental Dice Task* (MDT), requires subjects to generate a random sequence using the digits from 1 to 6. While previously applied successfully in a great variety of other contexts [3,5], random digit generation has also recently been employed in the context of spatial cognition [24]. There is now converging evidence from work with healthy subjects and neurological patients for a "number line" that extends from left (small numbers) to right (large numbers) in representational space [20,36,37]. Using the MDT, Loetscher and Brugger [24] have shown that normal subjects favor small over large numbers, a preference that must be viewed as equivalent to a "right-sided" inattention (pseudoneglect) in number space, as the observed small-number preferences can be influenced by the same variables that consistently shift individuals' attention in physical space.

Twenty men (mean age 22.0 years, S.D. 3.0) and twenty women (mean age 21.5 years, S.D. 2.6) participated in the study that was conducted according to the Declaration of Helsinki and had been approved by the Ethics Committee of the University of Victoria. Informed written consent was obtained from each subject. All subjects were right-handed according to a 13-item questionnaire [9], and none of them reported, in an extended interview, any prior history of neurological or psychiatric disease or of learning disabilities or substance abuse.

Breadth of categorization behavior was assessed with the 20-item CW scale, published in full in [30] along with construction criteria and validity, reliability and consistency data. On each item a score between 0 and 6 can be obtained; in the sample item a value of zero would be scored for the pairing of option "25 m.p.h" in (a) and option "12 m.p.h." in (b), i.e. the two extreme speeds most closest to one another. A 6 would be scored for option "105 m.p.h." in (a) and option "2 m.p.h." in (b), i.e. the two speed values 6 intermediate options apart. Over all 20 items, possible scores on the scale thus ranged from 0 (most narrow categorization) to 120 (broadest categorization).

This was a divided-visual field task with a total of 128 trials. For 64 trials, stimuli were line drawings of chimeric faces displaying a sad expression on one side and a happy expression on the other. In 50% of these trials, the happy half-face was presented to the left of the sad half-face, in the remaining 50%, this arrangement was reversed. For the other 64 trials, only one half-face was presented, either happy or sad and either to the left visual field (LVF) or the right visual field (RVF). Stimuli were presented using an Apple Macintosh computer and the software "Psychlab" [6]. Exposure time was 17 ms, and stimuli extended from 3.4° to 9.0° of visual angle to both sides in the case of chimeric faces and to either side in the case of half-faces, respectively. Participants fixated a cross displayed in the center of the visual field. In one run (64 trials), they were instructed to press the space bar with the index fingers of both hands as soon as they detected a happy half-face or if they considered the chimeric face to look happy rather than sad. In a second run with identical stimuli, they were instructed to respond to sad-looking faces. In both runs, 1500 ms were allotted for a manual response to a trial to be considered and, accordingly, participants were encouraged to decide as spontaneously and quickly as possible. Order of the two runs was counterbalanced across subjects. The variables of interest were the total number of trials in which subjects responded to the LVF part of a chimeric face and the number of trials in which they responded to the RVF part.

This task was described in detail elsewhere [14]. Briefly, subjects were blindfolded and had to center a rod (20 mm diameter) protruding from a small central tube after repeated tactile exploration using one hand at a time. By stroking down the rod from its right end to the right edge of the tube with the right hand, and by analogous left-sided exploration with the left hand, subjects decided which side was longer and adjusted the rod such that the left and right protruding parts appeared equal in length. Either side of the rod could be inspected first, and there was no time constraint as to inspection time or the number of adjustments. After a subject had indicated the completion of a trial, magnitude and direction of the lateral displacement was established to the nearest millimeter. In six trials, a short rod (65 cm), and in six trials a long rod (88 cm) was used. Initial placement of the rod was far to the right in half of the trials and far to the left in the other half. Rod length and initial placement were alternated pseudorandomly across trials. The variable of interest was the mean lateral displacement across the 12 trials (determined to the nearest millimeter). Note that, as both hands were involved in the centering procedure during each trial, performance of left and right hand could not be established separately.

This task requires subjects to generate a random sequence using the digits 1–6 [5]. Instructions emphasize that the produced sequence should be as indistinguishable from that produced by repeated rolls of a real die. Sixty-six paced (1 Hz rhythm) oral responses were collected. The variable of interest was the difference between the sum of call frequencies for digits 1, 2, and 3 ("left" in number space) and the sum for digits 4, 5, and 6 ("right" in number space). "Left" and "right" in number space reliably map onto left and right in both perceptual and representational space [36,37].

Mean score on the CW scale was 66.8 (S.D. 14.9), women (64.3, S.D. 15.1) not scoring differently from men (69.4 S.D. 14.6; $t(\text{d.f.} = 38) = 1.1$, two-tailed $p = .29$). Judged emotional facial expression of the 64 chimeric faces was more often cued by the LVF expression (19.8 trials, S.D. 10.1) than by the RVF expression (14.9 trials, S.D. 9.7; $t(\text{d.f.} = 39) = 2.1$, two-tailed $p = .042$). This LVF bias (i.e., the difference between the number of decisions cued by the LVF and those cued by the RVF) was comparable for women and men ($t(\text{d.f.} = 38) = .26$, two-tailed $p = .79$).

Since length of the rods in the rod centering task did not have any significant effects, data were collapsed over both rods. The subjective midpoint did not significantly deviate from the objective one for the whole sample (mean leftward deviation .21 cm S.D. 7.9; $t(\text{d.f.} = 39) = .17$, two-tailed $p = .87$) nor separately for the 20 women (mean leftward deviation 1.94 cm S.D. 8.2; $t(\text{d.f.} = 19) = 1.17$, two-tailed $p = .30$) or the 20 men (mean rightward deviation 1.52 cm S.D. 7.3; $t(\text{d.f.} = 19) = .93$, two-tailed $p = .36$). Deviations for women and men were of opposite sign, but not significantly different from one another ($t(\text{d.f.} = 38) = 1.41$, two-tailed $p = .17$).

Randomization quality in the MDT was comparable to the one described in earlier studies [23]. Specifically, women's and men's RNG indices [5] were not significantly different from one another ($t(\text{d.f.} = 38) = .10$, two-tailed $p = .92$). Judged from the observed frequencies of small (1,2,3) and large (4,5,6) numbers, there was no overall bias towards one side of number space, neither for the entire sample ($t(\text{d.f.} = 39) = .83$, two-tailed $p = .41$) nor for women and men separately ($t(\text{d.f.} = 19) = .56$, two-tailed $p = .58$, and $t(\text{d.f.} = 19) = .60$, two-tailed $p = .56$, respectively).

Magnitude of LVF bias in the chimeric faces task was significantly correlated with raw scores on the CW scale for the 20 men (Pearson $r = .42$, $p < 05$, two-tailed; Fig. 1, top), but not for the 20 women ($r = -.08$, $p = .73$), nor for the sample as a whole ($r = .17$, $p = .28$).

Leftward deviations in the rod centering task were unrelated to scores on the CW scale ($r = .05$, $p = .38$ for whole sample; $r = .01$, $p = .48$ both for the 20 women and the 20 men separately).

Over all subjects, the difference between the frequency of small and that of large numbers in the MDT was not correlated with raw scores on the CW scale ($r = .12$, $p = .22$). This correlation was significant, however, for the 20 men ($r = .45$, $p < .05$, two-tailed; Fig. 1, bottom), but not for the 20 women ($r = .16$, $p = .25$).

Over all 40 subjects, magnitude of the leftward biases in the three different spatial–attentional tasks were unrelated to one another ($-.06 < r < .18$; all p-values >.05). However, for the 20 men, the small-digit ratio in the MDT was tendentially correlated to the left-sided bias in the chimeric faces task ($r = .41$, $p = .09$, two-tailed; corresponding values for 20 women: $r = .04$, $p = .86$).

This study set out to explore the relationships between semantic space on the one hand and perceptuo-motor and representational space on the other hand. Semantic space was operationalized as healthy subjects' "category width", a measure once popular to differentiate between persons with fundamentally different cognitive styles (see [17,19] for review). In fact, categorization is at the heart of associative behavior and its functional-adaptive value consists in enabling us "to treat different things as if they were identical" ([26], p. 25). Healthy individuals diverge vastly in their willingness, inclination and

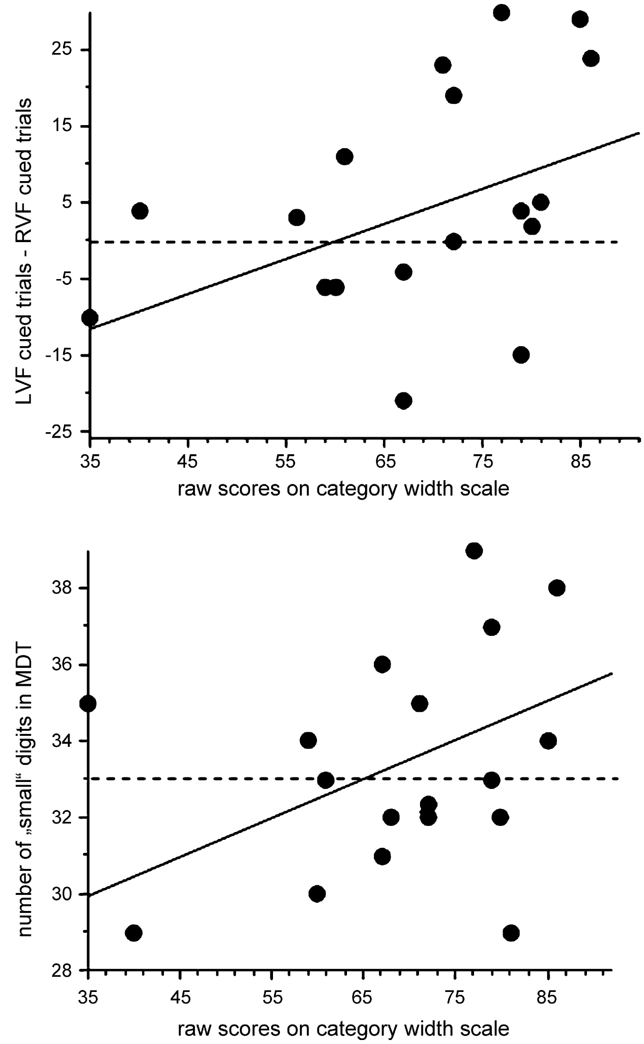

Fig. 1. Correlation of the 20 men's raw scores on Pettigrew's category width scale and left visual field (LVF) cuing relative to right visual field (RVF) cuing in a chimeric faces task (top) and bias for relatively small, "left-sided" numbers in random digit generation (bottom). The broader an individual's semantic space, the more he relied on left-sided information in visual-perceptual space and representational (number) space. Dashed horizontal lines indicate bias-free responding in the two tasks (i.e., as many left-sided than right-sided cues in the chimeric faces task and as many "small" as "large" numbers in the Mental Dice Task, MDT).

ability to see different things as identical. Arguably, those who limit their semantic associations within a narrow band note the differences between two objects easier than their commonalities. Conversely, those with a broad focus of their associational spotlight may do the reverse. When considering these two styles of association behavior, a specific dichotomy in the two cerebral hemispheres' functional specializations immediately springs to mind, namely the advantage of the LH for the analysis of close associations and the corresponding advantage of the RH for coarse, less focused, semantic analysis [2,27,33]. It is this type of hemispheric specialization for near and far semantic space that we attempted to relate to established, hemisphere-mediated lateral biases in perceptuo-motor space and to similar biases in number space. We will discuss our findings with respect to these two latter kinds of spaces separately.

In a purely perceptual task, i.e. the judgement of emotional expressions of chimeric faces, we found a clear bias for subjects' decisions to be based on the information in the LVF. This bias, well established in the previous literature [1], was significant for both the 20 women and the 20 men. Most importantly, as hypothesized, subjects' scores on the CW scale were positively correlated with the magnitude of this bias, indicating a relationship between the strength of RH spatial attention and an individual's preference for coarse associations, i.e. to a broad categorization behavior. This relationship between semantic and perceptual space was significant, however, only for the 20 men with not even a tendency evident for the 20 women (see below, for a discussion of this sex difference).

In contrast to the LVF bias in the chimeric faces task, lateral deviations in the tactile bisection task were entirely uncorrelated to subjects' category width. One reason for this null finding may be the fact that, both overall and for the two sexes separately, there were no significant deviations of the subjective from the objective midpoints, in other words: no pseudoneglect emerged. However, presence of a pseudoneglect on the group level is not a necessary precondition for a correlation between size of individual deviations and other behavioral measures to be observed. For instance, one research group has found that the magnitude of schizophrenic patients' left-sided tactile bisection errors was correlated to the severity of their psychotic symptoms [14], while another group found the same measure correlated to healthy subjects' scores on a schizotypy scale (notably only in men, but not in women) [4]. In both these studies, the left-sided deviations (pseudoneglect) were not significant overall. An alternative explanation for the absence, in our study, of a relationship between category width and tactile bisection performance is that the task of finding the midpoint of a rod while blindfolded primarily depends on motor-explorative behavior. This part of the spatial orienting process may be (1) less strongly linked to cognitive variables and (2) less strongly reliant on one single hemisphere (note that both hands could be used in exploring the rods).

There is convincing experimental and clinical evidence that the horizontal dimension of number space is organized along a number line that extends from left to right in subjects with a native language written from left-to-right [10,12]. In particular, patients with RH lesions and left-sided neglect not only deviate towards the right in bisecting physical lines, they also deviate towards large numbers ("to the right") when required to indicate the number that halves the distance between two points on the number line [37]. Also, comparing numbers with a given standard, they commit more errors for small compared to large numbers [36]. We have recently shown that random digit generation provides an alternative means to explore asymmetries in number space. We found that healthy subjects showed a consistent preference for small over large numbers, that is, in analogy to left-ward shifts in spatial attention tasks, they evidenced a "pseudoneglect in number space" [24]. While an overall pseudoneglect was not evident in the present experiment, most importantly, as hypothesized, the magnitude of individual small-number biases was correlated to scores on the CW scale. That this relationship was exclusively found for the 20 men is in accordance with the findings in the chimeric faces task, and will be discussed in the following paragraph. Thus our results show that, at least for males, a relative bias for broad association/categorization in semantic space is accompanied by a relative bias for directing attention to the left side of representational, i.e. number space. Since both types of biases have individually been related to RH mediation in previous research, we propose that the correlation observed between them in the present research reflects the relative strength of reliance on a common underlying RH process.

Lateral biases in perceptuo-motor and number space were not significantly related to one another. This statistical independence seen in our normal sample is consistent with the double-dissociation, seen in patients with right parietal lesions, between neglect in visuo-motor space and neglect for the mental representation of space [28,29]. Specifically in the case of neglect in number space, recent work has shown a relative independence of number line bisection errors and the deviations in the bisection of physical lines [11].

We assume that men's stronger coupling between category width and lateral biases in both perceptual and number space is due to the more pronounced hemispheric specialization of the male brain [34]. In a little known article, Paul MacLean had somewhat poetically noted with respect to the LH's dominance for language functions, that "... the minds of women sail in a vessel less tilted to the left than do those of men" ([25], p. 422). Neuroimaging work has long since quantified these differentially pronounced tilts for women and men [34], whose importance for neuroscience appears about to be rediscovered [8]. In the present population, if coarse associative categorization was more uniformly represented by the RH in our male participants, sex differences in the correlations, especially for emotional facial expressions (an almost prototypically "right hemispheric" function) would almost automatically emerge. A further point to be considered is that, in women, the magnitude of functional hemispheric asymmetries is modulated by the menstrual cycle [15,16]. Specifically, Hausmann et al. [15] have shown that different lateralized tasks are differently affected by hormonal fluctuations over the cycle. Hence, we would expect correlations between different task performances to be lower in a group of randomly selected women compared to those within a comparably large group of men. The fact that we found the correlations between categorization behavior and lateral biases in space exploration significant exclusively for our male participants does not indicate that an interdependence between semantic and physical space would be the sole property of the male brain. We would predict that during periods of low female sex hormones (i.e. in the menstrual phase), the female brain would not only be more strongly lateralized, but also evidence the "male pattern" of spatial-linguistic coupling.

Evidently, at least among men, breadth of categorization behavior is related to horizontal attentional asymmetries in both physical and representational space. This finding adds to the growing literature on the intimate relationships between spatial cognition and language processing [32,38]. It is also compatible with models of overinclusive thinking as a consequence of the particularly coarse semantic processing style of the RH—the one hemisphere whose attention is clearly directed to the left side of space [13,31,35]. Considering that correlations between different laterality measures within the domain of language are usually low or absent altogether (see, e.g., [22]) the correlations reported here are intriguing. As modest as they are, they are relevant to an understanding of the similarities between creativity and madness, which have long been noted by popular and scientific minds [13]. While overly remote, delusional associations have been linked to exaggerated left-sided spatial exploration [14], the oblique associations and the broad categorization behavior characteristic of verbal creativity have not, to our knowledge, been examined in relation to hemispatial preferences. We predict that the simultaneous investigation of semantic and spatial functions will significantly contribute to neuropsychiatry and to the psychology of creativity alike.

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