EFFECTS OF FOCAL BRAIN DAMAGE ON CATEGORIZATION OF VISUAL AND HAPTIC FEATURES

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ABSTRACT

Previous research has shown that stimulus values on a sensory continuum are perceived in a categorical manner by human subjects and by rhesus monkeys (Wilson, 1972; Streitfeld & Wilson, in press). That is, stimuli which are judged to belong to different perceptual categories are discriminated more accurately than are stimuli which are perceived as belonging to the same perceptual category. In these experiments, the category boundary was defined as the adaptation level (AL) established by the stimulus series presented to the subject. Wilson and DeBauche (1981) showed that resection of visual "association cortex" in monkey abolished categorical perception of visual features and they hypothesized that modality-specific neural substrates that preserve the effects of stimulation provide an internal referent which determines the manner in which given stimulus values are identified and discriminated. In the study described here, the effects of focal brain damage on categorical perception of three stimulus continua was examined in neurological patients. Processing of visual features as members of perceptual categories was doubly dissociated from processing of haptic stimuli; posterior lesions in the right hemisphere selectively impaired categorization of visual stimuli differing in length and orientation while anterior lesions in the left hemisphere selectively impaired categorical perception of weight. Implications for the neural dynamics of categorization are discussed in the context of AL theory and principles of neural organization.

BACKGROUND

Adaptation-level theory (Helson, 1948, 1964) postulates that perceptual judgments in a given sensory domain are based on an internal standard, the adaptation level (AL), the value of which is determined by a weighted, logarithmic mean of focal, background and residual stimulation. The AL represents a neutral point of functioning, i.e., the level of stimulation to which the organism is adapted or habituated. It follows that stimuli whose values coincide

with the physical value representing the AL will elicit a null response while stimulus values that differ from the AL will elicit perceptual responses which depend upon the direction and magnitude of their discrepancy from the AL. In this sense, the AL can be equated with a category boundary, structuring a stimulus continuum into two complementary perceptual classes. For a series of stimuli differing in length, for example, stimuli whose physical values lie above the AL would be perceived as "long" while stimuli whose values lie below the AL would be perceived as "short". In studies with rhesus monkeys, Wilson (1972) showed that the discriminability of stimuli, as well as the way in which stimuli are identified (i.e., assigned to perceptual classes), is a function of their relationship to the AL. Two stimuli that lay on different sides of the AL (a "long" vs. a "short" stimulus) were discriminated more accurately than two stimuli that lay on one or the other side of the AL (two "long" or two "short" stimuli) even though the physical difference between the stimuli in the pairs was the same.

Subsequently, Wilson & DeBauche (1981) showed that lesions of visual association cortex, but not primary visual cortex, in monkeys interfered with categorical perception of three visual continua. It was hypothesized that portions of the extrastriate visual system, including inferotemporal cortex and the pulvinar nucleus of the thalamus, serve to maintain reverberatory circuits which sustain the effects of visual experience over time. Such a system would yield an experience-sensitive "set-point" or frame of reference against which visual input is compared.

The experiments reported here were designed to further test the hypothesis that categorical perception in humans, as in monkeys, is vulnerable to forebrain damage which involves cortical areas that lie outside primary sensory cortex (Wilson, in press). To this end, we examined visual and tactual-kinaesthetic discriminative abilities in patients with verified damage to restricted brain areas. While our data do not allow us at this time to contrast the effects of damage to primary sensory cortex vs. intrinsic or "association" cortex, we can address the issue of whether modality-specific impairments in categorization follow from damage to specific extrasensory brain areas.

METHOD

Subjects.

Neurosurgical patients who had sustained focal forebrain damage due to vascular accident, trauma, or removal of localized tumor, served as subjects on a voluntary basis. Not all patients participated in all tests. Subjects were recruited at one of two centers, either Hartford, CT or Winnipeg, Manitoba and were identified by medical staff as having sustained damage appropriate to the

investigation. Location and extent of brain damage was confirmed by reference to radiological data and/or surgical reports.

Procedure.

Four sensory continua were investigated for evidence of presence or absence of categorical perception as a function of locus of brain damage. Stimuli on two visual continua, line length and orientation (angular disparity from the horizontal), and two tactual-kinaesthetic continua, line length and weight, were presented. Data for tactual judgments of line length are not presented here as only a small number of patients have been tested on this task to date. For judgments of visual length, black bars 2 mm thick which ranged in length from 33-38 mm in 1 mm increments were mounted on 10 cm^2 white cardboard. For the orientation task, bars of equal length were varied in orientation from 38-48 deg in 2 deg increments. The stimuli for judgments of weight were small vials of identical size and appearance which were filled with lead shot and cotton packing, and which ranged from 100 to 150 gr in 10 gr increments.

For all tasks, the six stimuli on the continuum were presented in pairs representing all possible combinations. The subjects were instructed to indicate by pointing to one of the stimuli in a given pair which was judged to be longer, more horizontal, or heavier. Visual stimuli were exposed for 2 sec. For weight judgments, subjects lifted each stimulus once prior to making a response. The left-right position of each stimulus and the position of the correct response were balanced over trials. No information was provided about the correctness of response. The 15 possible combinations of the six stimuli on each continuum were each presented five times, making a total of 75 trials for each stimulus condition.

Data Analysis.

The category boundary was calculated for each subject individually. For the visual length continuum, for example, the percentage of choices of each stimulus as "longer" was computed, and the stimulus value that was chosen 50% of the time was identified as the AL (the category boundary between stimulus values that were perceived as "long" and those that were perceived as "short"). This value fell between the two middle stimulus values in the set for most subjects, consistent with AL theory which predicts that the pooled effect of the physical values in the series presented determines the neutral point in the absence of background or residual factors. After the location of the boundary was established, percentage correct response was calculated for pairs of stimuli in which both stimuli lay on one side of the boundary (Within-category discriminations), and for pairs in which the stimuli straddled the category boundary (Between-category discriminations). This was done for one-step and two-step differences between the stimulus values on each sensory continuum.

RESULTS AND DISCUSSION

Mean percentage correct discrimination for Between-category pairs vs. Within-category pairs is shown in Table 1 for the two visual discrimination tasks and for weight discrimination. It can be seen that for visual length discrimination, neither left nor right-hemisphere frontal damage affected categorical perception while performance was severely compromised by damage to right temporal cortex. Similarly, damage to right temporal and right parietal-temporal cortex selectively affected categorical perception of visual orientation, in contrast to lesions in other areas which did not interfere with categorization. On the weight discrimination task, both left frontal and left parietal-temporal damage appeared to abolish categorical perception but the results for judgments based on use of the hand ipsilateral to the lesion suggest that left frontal cortex is the critical area for categorization of this dimension. That is, the data from the ipsilateral hand are more compelling in terms of localizing the neural substrate for categorization of a weight continuum since such judgments are less likely to be degraded by direct effects on the sensory projection system. It should be noted that Within-category discrimination accuracy is not impaired in those groups which fail to show the category-boundary effect.

These data provide evidence on several points. First, Between-category judgments are more accurate than Within-category judgments for most patients on most of the tasks, indicating significant categorical perception of nonverbal stimuli in spite of forebrain damage. The effects are similar in degree to those exhibited by neurologically-intact subjects tested by Streitfeld & Wilson (in press). Thus, categorical perception appears to be a relatively robust phenomenon from a neuropsycholgical perspective in the sense that it is not vulnerable to all brain injury. On the other hand, deficits in categorization in specific sensory domains resulted from damage to localized areas of association cortex. Perception was not categorical for either visual length nor visual orientation following damage to the right temporal cortex, in contrast to categorical perception of weight which was affected by damage to the left frontal areas of the brain. Patients with damage to parietal-temporal cortex in the right hemisphere were impaired in categorical perception of visual orientation but not visual length. These results suggest that categorization of stimulus features is a modality-specific process that occurs independently within portions of the thalamocortical system devoted to each sensory channel. Moreover, the results are consistent with the notion that categorical perception depends upon stored representations of experience in a particular sensory domain since the AL defined the category boundary for each of the sensory continua examined.

Taking previous findings into account, the data suggest further that damage to intrinsic or "association" areas in the frontal,

parietal, and temporal lobes is sufficient to produce impairments in categorical perception, independent of primary sensory deficit.

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AUTHOR NOTES

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TABLE 1

MEAN PERCENTAGE CORRECT DISCRIMINATION FOR COMBINED ONE-STEP AND TWO-STEP DIFFERENCES BETWEEN STIMULI ON THREE SENSORY CONTINUA.

Lesion Group	N	Between-category	Within-category	Between-Within difference
		Visual Length		
LF	4	98	78	20
LPT	3	85	77	8
LT	2	93	70	23
RF	8	95	72	23
RPT	7	82	69	13
RT	5	75	73	2
		Visual Orientation		
LF	2	83	74	9
LPT	2	85	70	15
LT	1	100	80	20
RF	3	83	64	19
RPT	4	77	77	0
RT	4	76	77	-1
		Weight (contralateral hand)		
LF	2	75	71	4
LPT	3	62	76	-14
LT	4	80	69	11
RF	7	80	68	12
RPT	8	77	66	11
RT	4	75	63	12
		Weight (ipsilateral hand)		
LF	3	75	77	-2
LPT	2	89	77	12
LT	3	97	75	22
RF	6	84	68	16
RPT	5	81	71	10
RT	4	88	73	15

NOTE: Lesion groups are LF (Left Frontal); LPT (Left Parietal-Temporal); LT (Left Temporal); RF (Right Frontal); RPT (Right Parietal-Temporal); RT (Right Temporal).