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PSYCHOPHYSICS WITH THE SPLIT-BRAIN SUBJECT: ON HEMISPHERIC DIFFERENCES AND NUMERICAL MEDIATION IN PERCEPTUAL MATCHING TASKS*

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Abstract—Two questions concerning the mediation of psychophysical scaling of lateralized stimuli were investigated in commissurotomized patients: (I) Is cross modality matching mediated by subvocal number assignment? (II) Are there hemispheric differences in psychophysical scaling? When exponents of power functions characterizing the magnitude estimation of joint position in right and left hands and line length in right and left visual fields were compared between the hemispheres, only the left hemisphere was able to make such judgments. When exponents of functions characterizing the cross modality matching of these stimuli were compared between the hemispheres, there were no significant differences. These results argue against mediation of cross modality matching by subvocal number assignment, and this demonstration of symmetrical transduction of univariate stimuli suggests a reinterpretation of the literature reporting perceptual asymmetries.

THIS study addresses two questions concerning the mediation of psychophysical scaling. (I) Are psychophysical judgments mediated by numerical assignment whether stimuli are scaled by proportional number production, or by proportional magnitude production? (II) Do the separated hemispheres produce different psychophysical scaling functions of the same stimuli?

Numerical mediation of psychophysical scaling: Background and rationale

Psychophysical research in many laboratories has shown that the relationship between the intensity of stimulation and the experienced sensation is a power function. This psychophysical law

$$\psi = \kappa\phi^{\beta}$$

indicates that sensation ψ increases in proportion to the physical intensity of the stimulus ϕ, raised to the power β. β depends upon the specific modality under consideration.

All psychophysical methods requiring judgment on the part of the observer have been criticized (e.g. [1]) as another form of the introspectionism of the late 1800s. It has been argued that the estimation of sensation is not possible, only the judgment of stimuli is possible ([2], cited in [3]). Such philosophical arguments are refuted by the replicability and

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predictability of the results obtained, especially from the "direct" psychophysical methods which (a) ask the subject to respond to the magnitudes of sensations produced by stimuli, and (b) consider the subject's responses to be meaningful judgments of those sensations, although susceptible to biases and distortions of various types [4]. For example, when subjects assign numbers proportionally to the loudness of white noise (magnitude estimation), the exponent β is roughly 2/3. If they judge brightness in the same way the exponent is 1/3. If they are then asked to match brightness to loudness (cross modality matching) the resultant exponent is predicted to be the ratio of the two exponents obtained from magnitude estimation, namely $(2/3)/(1/3) = 2$, and it is [5].

This transitivity between magnitude estimation (ME) and cross modality matching (CMM), and the replicability of results across experiments and laboratories has produced confidence in the power law, in direct scaling methods and specifically in the use of ratio-scale numerical judgments, i.e., ME.

It has, however, been argued that results from CMM as well as from ME are due to subvocal numerical mediation of CMM responding ([6]; and see [3], pp. 108–110). That is, the subject internally produces a number in response to the stimulus, and makes an overt response to the number so produced (see [6], p. 9 for a more formal description). If this is in fact the case, then the transitivity between ME and CMM results is tautological and should not increase our confidence in the validity of direct scaling methods.

One aim of the present study was to investigate the ability of each separated hemisphere of commissurotomized patients to perform CMM and ME judgments of lateralized stimuli. The ability of the right hemisphere of these patients to make CMM judgments in light of a demonstrated inability to make ME judgments of those same lateralized stimuli, or to read or calculate, would be interpreted as evidence against the necessity for mediation in CMM judgments by number assignment and consequently as support for direct scaling in general.

Hemispheric differences in psychophysical scaling: background and rationale.

The use of psychophysical techniques allows an objective investigation of the presence of so-called "perceptual" hemispheric asymmetries. Tasks which require discrimination between stimuli varying along one perceptual dimension (referred to in the literature as "perceptual" or "univariate" stimuli) have been reported to elicit a right hemisphere advantage. This advantage has been attributed to asymmetrical perceptual processing. In the visual system, normal Ss show greater accuracy or speed in processing stimuli presented to the left visual field (LVF) in tasks of dot localization, dot enumeration, line orientation matching [7–9] and tasks of same–different discrimination of curvature [10], line orientation [11, 12] and lightness perception [13]. In patient populations, same–different tasks of univariate discrimination (i.e. discrimination of line orientation, dot position, line length and gap size) are performed most poorly by patients with right posterior lesions [14, 15]. Similarly dependent on right hemisphere processing are both stereopsis [16–18] and the McCollough effect, a long-term after-effect contingent on grid orientation and movement [19–21].

In the somatosensory system SEMMES *et al.* [22] observed a positive relationship between the degree of impairment in discrimination touch and the proximity of damage to the sensorimotor areas in patients with left but not right hemisphere lesions. Recently, BENTON *et al.* [23] observed that the left hand of normal subjects performed more accurately in cross-modal recognition of tactually presented line direction. SEMMES [24] has interpreted her own and corroborating data [25, 26] as support for a model of hemispheric specialization which postulates more focal somatomotor representation in the left hemisphere, giving rise to the language system, and more diffuse organization in the right hemisphere, viewed as consistent with the development of spatial abilities.

Despite wide agreement on the specific involvement of the right hemisphere in some discrimination tasks, there is no consensus on the nature of its contribution. Reports of greater right hemisphere "perceptual" competence use stimuli and tasks that are similar to those used in studies which interpret a right hemisphere advantage as indicating lateralized "spatial ability" (e.g. [27–29]). In contrast to the widely held spatial interpretation, WARRINGTON and RABIN [14], also using univariate stimuli, attributed deficient discrimination by patients with right posterior lesions to a breakdown in "visual sensory" performance *per se*. Similarly, KIMURA and DURNFORD [7] interpreted the right hemisphere advantage they observed on dot enumeration and line orientation discrimination tasks as evidence for a "perceptual" as opposed to a "spatial" basis of laterality effects mediated in striate cortex.

The second question in the present study concerned differential hemicortical contributions to the central transduction of univariate stimuli. Psychophysical scaling techniques provide an objective way to ask that question. Patients who have undergone forebrain commissurotomy for medically intractable epilepsy are ideal subjects for inquiry into the relation between stimulus magnitude and sensation magnitude in psychophysical tasks performed by each separated hemisphere. Psychophysical techniques can measure whether the separated hemispheres scale univariate stimuli in fundamentally different ways, as reflected in the exponents describing the subjective magnitude of stimuli relayed to each separated hemisphere. While the observation of reliable differences in exponents of functions produced by each hemisphere would be an extension of the literature reporting asymmetrical processing of univariate stimuli, the opposite result would suggest that sensory transduction of such stimuli, as measured by psychophysical scaling functions, does not proceed asymmetrically.

METHOD

Subjects

Five right-handed male epileptics who had previously undergone partial or complete forebrain commissurotomy to control the interhemispheric propagation of seizures were paid for their participation in this study. As determined by the surgeon (D.H.W.), the extent of commissure section differed among Ss. To determine the degree of interhemispheric transfer, these Ss have been extensively tested for their abilities to name dichotically presented auditory stimuli and to name and match lateralized visual and tactile stimuli (e.g. [30, 31]). These Ss have also been given tasks of same–different matching [32] and stereoscopy [33]. Based on these results and similar testing done in the context of this study, Ss were classified as follows: P.S. was both visually and somesthetically split, both D.H. and J.Kn. were somesthetically but not visually split, J.H. was visually but not somesthetically split and J.K. exhibited no perceptual or motor consequences of partial commissurotomy.

Responses

In separate sessions, Ss were required to judge perceived stimulus magnitude both by verbal ME judgments and by non-verbal CMM judgments. ME is a direct measure of perceived stimulus magnitude. Ss were instructed to make ME judgments by proportional assignment of numbers to perceived stimulus magnitude. Such verbal judgments also indicated whether stimulus presentations were lateralized as evidenced by Ss' ability to make meaningful CMM but not ME judgments of stimuli confined to the right hemisphere. The CMM responses were made by closing a push button switch mounted so that pressure from both thumb and forefinger were required to close it. An attached timer provided the response measure of button press duration. The S was instructed to press the button for a duration proportional to perceived stimulus magnitude. This CMM response permitted a non-verbal assessment of the psychophysical scaling function produced by each hemisphere.

Tasks

A. Psychophysical scaling tasks. Ss were required to produce both ME and CMM judgments of lateralized tactile and visual stimuli which varied only in magnitude within each modality. Stimulus values were selected by two criteria: a roughly 30:1 subjective range (based on previously reported exponents) and a geometric progression. All stimulus values were presented in random order with the constraint that each hemisphere was stimulated twice with every stimulus value within a task replication. Ss were initially instructed in making proportional judgments on two non-lateralized training tasks, i.e., CMM of number and ME of line length.

The tactile task required judgments of a series of 10 dowels, 1 inch in diameter, which ranged in length from 5 to 135 mm. Out of sight of the S, these stimuli were placed briefly between thumb and forefinger. This task was designed to compel judgment of joint position. Joint position in the primate has been demonstrated to have only contralateral representation [34, 35]. GAZZANIGA *et al.* [36] have demonstrated solely contralateral representation of distal extremities such as thumb and forefinger in commissurotomized subjects. In the visual task, vertical lines varying between 6 and 180 mm in length were presented tachistoscopically for 150 msec through a timer-operated shutter attached to a projector. The S was instructed to fixate a central dot on the screen and the stimulus appeared 2 degrees from the fixation point. The experimenter delivered the stimulus when the subject appeared to be fixating the dot. Normal room lighting eliminated ambient brightness cues to the S.

All tactile stimuli were presented and all CMM duration responses were made by placing the appropriate hand(s) in a foam-lined box to prevent the stimulated hemisphere from seeing and guiding the responses of the ipsilateral responding hand by cross-cuing strategies [37]. For each stimulus modality, CMM judgments were made both with the hand ipsilateral and with the hand contralateral to the stimulated hemisphere.

B. Tasks to assess the mediation of CMM. KRANTZ [6] has suggested that the consistency of CMM and ME judgments may be due to numerical mediation of CMM tasks. In light of the difficulty of directly determining the use of number assignment in CMM, the potential for such mediation by the right hemisphere was assessed by measuring its arithmetic and receptive verbal capabilities. These non-psychophysical tasks varied according to the specific deficits of each S. To assess calculation abilities, simple problems of addition, subtraction, multiplication and division were administered to each visual field of visually split Ss by tachistoscopically presenting pairs of digits. Before each series, Ss were informed which operation to perform on the numbers and after each presentation were requested to first verbally report the stimulus and then point to the correct answer. Since only very rarely were Ss able to name LVF stimuli, an accurate verbal report of the stimuli presented in the LVF indicated the S was not centrally fixated when the stimulus was presented. For tactually split Ss, pairs of three-dimensional numbers were presented to each hand separately. Tactually split Ss were never able to accurately report stimuli in the left hand. Before the stimuli were presented, Ss were informed of which operation to perform and afterwards were required to point to the correct answer. For division, the S was given a different divisor on each trial, asked to give a verbal report of visually presented stimuli and required to point to the correct quotient after each lateralized presentation of the dividend. Patients' abilities to read simple concrete nouns in the right hemisphere were tested by either lateralized tactual or tachistoscopic visual presentations of concrete nouns to the left hand or to the visual fields, respectively. Ss were asked to respond by pointing to one of four pictures in visual presentations and one of ten letters in tactual presentations.

RESULTS

Logarithms of the geometric means of the psychophysical judgments were regressed against the logarithms of physical stimulus magnitude. The slope of the regression line is the least squares estimate of the power function exponents. In Tables 1 and 2, b is the exponent or slope of the regression line and r^2 is the percentage of variance accounted for by the linear regression fit to the data. Psychophysical data were grouped by combining replications of tasks across functionally similar Ss. The resultant exponents were subjected to t-tests between exponents of interest. Adjusting the error rate for multiple comparisons required that each t-value be tested at a significance level of 0.002 ([38], p. 489). However, where no differences are claimed, the probability level was greater than 0.05.

Whether initially lateralized stimulus information remains confined to a hemisphere in a given S is defined by the ability of that S to verbally judge stimuli relayed to the mute right hemisphere. An S unable to verbally judge stimuli presented to the right hemisphere in a given modality is considered to be functionally "split" in that modality. In using this definition, it is assumed that any information relayed to the left hemisphere, either directly or interhemispherically, will have access to the language system.

Table 1. t-tests of exponents from judgments of finger span stimuli

Group	Task	r^2	b	r^2	b	$t(df=8)$
Split	ME	RH: 0.95	0.63	LH: 0.18	0.17	4.60*
N-Split	ME	RH: 0.99	0.74	LH: 0.98	0.76	0.88
Split	CMM	RH: 0.83	0.39	LH: 0.85	0.38	0.11
N-Split	CMM	RH: 0.89	0.39	LH: 0.79	0.35	0.59
S vs NS	CMM	S–RH: 0.83	0.39	NS–RH: 0.89	0.39	0.09
S vs NS	CMM	S–LH: 0.85	0.38	NS–LH: 0.79	0.35	0.37
S vs NS	CMM	S–SRRL: 0.97	0.46	NS–SRRL: 0.92	0.36	2.20
S vs NS	CMM	S–SLRR: 0.62	0.25	NS–SLRR: 0.91	0.40	1.80

* $P<0.002$.
r^2 = percentage of variance accounted for by the linear regression fit to the data.
b = exponent or slope of the regression line.
S = grouped data from tactually split Ss.
NS and N-Split = grouped data from Ss not tactually split.
ME = magnitude estimation.
CMM = cross modality matching.
RH = stimulate right hand, responds with right hand.
LH = stimulate left hand, responds with left hand.
SRRL = stimulate right hand, respond with left hand.
SLRR = stimulate left hand, respond with right hand.

Table 2. t-tests of exponents from judgments of line length stimuli

Group	Task	r^2	b	r^2	b	$t(df=8)$
Splits	ME	RVF: 0.99	1.03	LVF: 0.08	0.07	10.10*
N-Split	ME	RVF: 0.97	0.64	LVF: 0.93	0.64	0.10
S vs NS	ME	S–RVF: 0.99	1.03	NS–RVF: 0.97	0.64	6.22*
S vs NS	ME	S–LVF: 0.08	0.07	NS–LVF: 0.93	0.64	5.42*
Split	CMM	RVF–RH: 0.71	0.44	RVF–LH: 0.60	0.52	0.46
Split	CMM	LVF–RH: 0.66	0.32	LVF–LH: 0.80	0.48	1.39
Split	CMM	RVF–RH: 0.71	0.44	LVF–LH: 0.80	0.48	0.33
Split	CMM	RVF–LH: 0.60	0.52	LVF–RH: 0.66	0.32	1.19
N-Split	CMM	RVF–RH: 0.90	0.51	RVF–LH: 0.97	0.55	0.53
N-Split	CMM	LVF–RH: 0.88	0.51	LVF–LH: 0.95	0.49	0.19
N-Split	CMM	RVF–RH: 0.90	0.51	LVF–LH: 0.95	0.49	0.27

* $P<0.002$.
r^2 = percentage of variance accounted for by the linear regression fit to the data.
b = exponent or slope of the regression line.
RVF = stimuli presented in right visual field.
LVF = stimuli presented in left visual field.
For other abbreviations, see Table 1.

Tactile Task

A. Magnitude estimation. Tactually split Ss (P.S., J.Kn. and D.H.) were able to make meaningful verbal judgments (ME) of joint position in right but not in left hands. The difference between exponents of grouped data was significant. All values for the finger span task are contained in Table 1. Figure 1 illustrates the apparent inability of split Ss to verbally describe information relayed through the left hand. In contrast, non-tactually split Ss made proportional verbal judgments of joint position in either hand which did not differ significantly from each other.

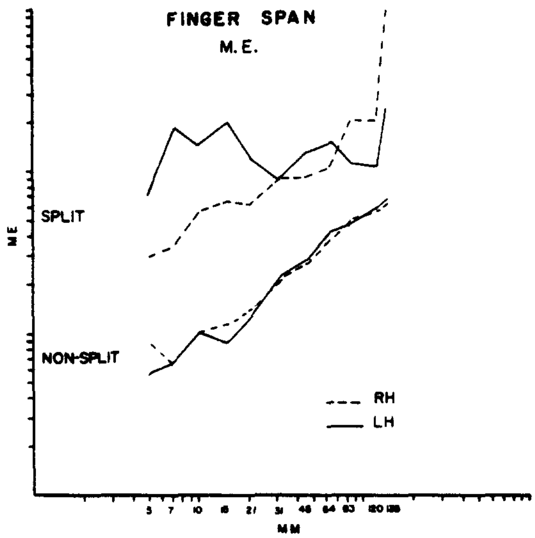

FIG. 1. Geometric mean magnitude estimation (ME) judgments (ordinate) of finger span stimuli (abscissa) by tactually split (upper plot) and non-tactually split (lower plot) patients. In this and the following figures, the upper plot is shifted up one cycle in order to display both plots. RH and LH designate responding by the right and left hands, respectively.

B. Cross modality matching.

1. *Intramanual judgments: responding by the stimulated hand.*

Direct assessment of hemispheric differences in transduction of joint position information was made by comparing exponents of CMM judgments of thumb and forefinger joint position between responding hands. No significant differences were found in grouped data under these conditions whether or not Ss were somesthetically split (Fig. 2).

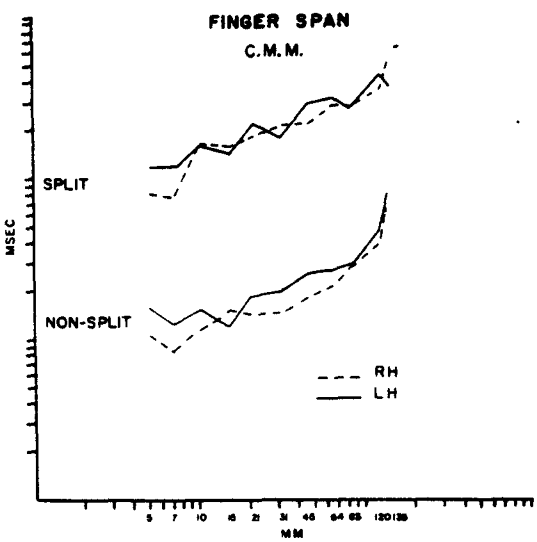

FIG. 2. Geometric mean duration (CMM) judgments (ordinate) of finger span stimuli (abscissa) under *intramanual* conditions by tactually split (upper plot) and non-split (lower plot) patients. RH and LH designate responding by the right and left hands, respectively.

2. *Intermanual judgments: responding by the hand contralateral to the stimulated hand.*

Also of interest were exponents of functions produced when the responding hand was contralateral to the stimulated hand, and thus ipsilateral to the stimulated hemisphere. In Ss who are functionally split in the presented stimulus modality, information about the stimulus cannot be transferred interhemispherically in this modality. Therefore, if a motor response is required of the hand normally controlled by the non-stimulated hemisphere, that hand can make appropriate responses only if the stimulated hemisphere can exert control over the stimulated (or ipsilateral) hand. Fine motor control of independent finger movements is exerted only by the crossed pyramidal motor pathways [39]. However, the independent finger movements used to press a button with opposing movement of thumb and forefinger for a duration proportional to perceived stimulus magnitude require afferent information concerning only the presence or absence of stimulation. Therefore, it may not be surprising that tactually split Ss were able to make duration judgments by ipsilateral motor control. In contrast, these Ss were consistently unable to make non-psychophysical intermanual matches of objects not easily labelled and presumably not dependent on left hemisphere language processes for coding.

Under intermanual conditions, somesthetically split Ss made CMMs of joint position in each hand that did not differ significantly (Fig. 3). There were no significant differences in similar comparisons of grouped data from Ss not tactually split. Nor were significant group differences obtained between split and non-split Ss in either intramanual or intermanual matching performance.

B. Visual Task

Direct comparisons of exponents characterizing the ME of line lengths in each visual field of visually split Ss revealed significant differences. All *t*-values and exponents for this task

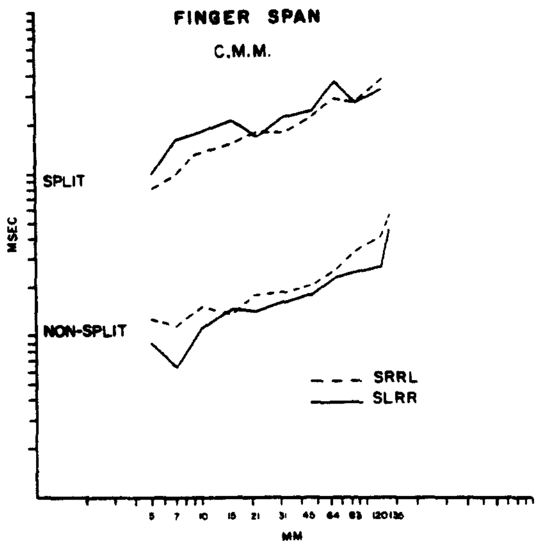

FIG. 3. Geometric mean duration (CMM) judgments (ordinate) of finger span stimuli (abscissa) under *intermanual* conditions by tactually split (upper plot) and non-split (lower plot) patients. SRRL designates stimulation of the right hand and responding by the left hand. SLRR designates stimulation of the left hand and responding by the right hand.

appear in Table 2. It can be seen from Fig. 4 that this difference is due to the inability of these Ss to verbally judge stimuli relayed to the right hemisphere. In contrast, exponents obtained under the same conditions from Ss not visually split were not significantly different. The exponent from ME judgments in the LVF by Ss not visually split was significantly higher than the exponent from visually split Ss. Not predictable, however, was a significant difference obtained between visually split and non-split Ss judging lines by ME in the RVF (left hemisphere). This difference is attributable to the relatively large exponents produced by

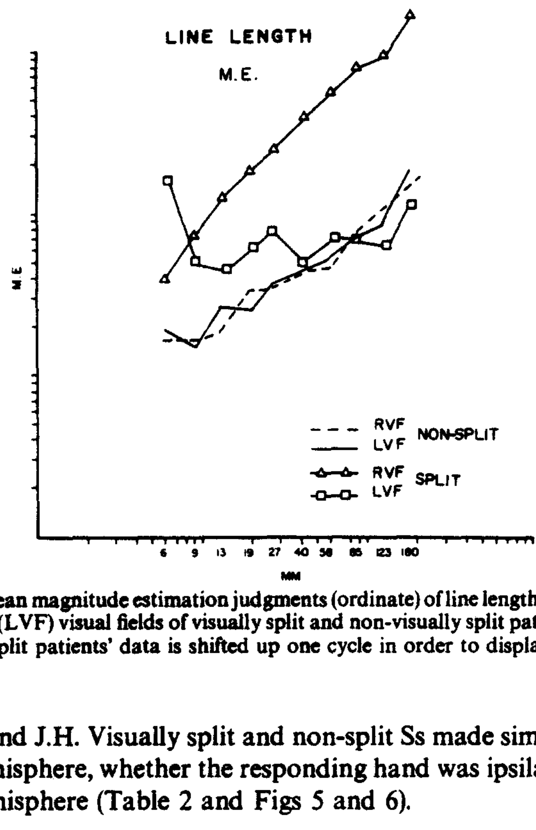

FIG. 4. Geometric mean magnitude estimation judgments (ordinate) of line length stimuli (abscissa) to right (RVF) and left (LVF) visual fields of visually split and non-visually split patients. The plot from visually split patients' data is shifted up one cycle in order to display both plots.

visually split Ss P.S. and J.H. Visually split and non-split Ss made similar CMMs of stimuli presented to each hemisphere, whether the responding hand was ipsilateral or contralateral to the stimulated hemisphere (Table 2 and Figs 5 and 6).

Verbal–numerical mediation of CMM

Only P.S. was at all able to read concrete nouns in the LVF-right hemisphere (Table 3). While P. S. could with some success add pairs of single digits entered through the LVF, and less successfully multiply and subtract such numbers, overall performance of his right hemicortex was consistently inferior to that of the left. Performance was particularly poor in dividing a two-digit dividend (Table 4). J.H. exhibited no ability to read in the right hemisphere and only rudimentary ability to add, while adding in the RVF was relatively unimpaired. D.H. was totally unable to add tactually in the left hand and J.Kn. performed below chance. Neither of these two Ss could correctly make more than one tactile–visual match of letters or numbers in the left hand, while both demonstrated some imperfect ability to do so in the right hand. Nevertheless, all these Ss made similar CMM responses of stimuli confined to the right hemisphere.

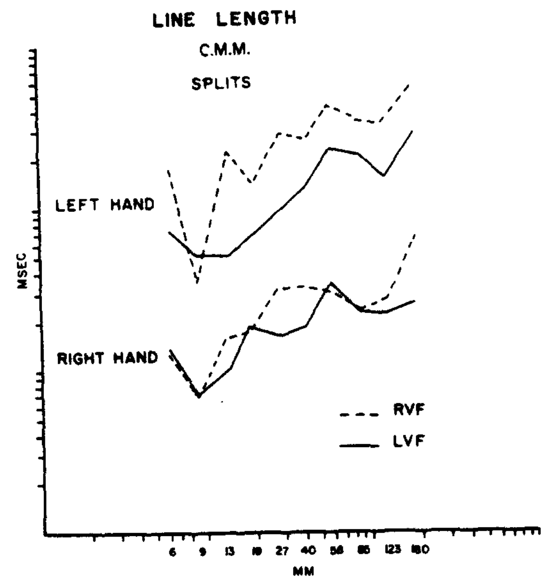

FIG 5. Geometric mean duration (CMM) judgments (ordinate) by left (upper plot) and right (lower plot) hands of line length stimuli (abscissa) presented to right (RVF) and left (LVF) visual fields of visually split patients. RH and LH designate responding by the right and left hands, respectively.

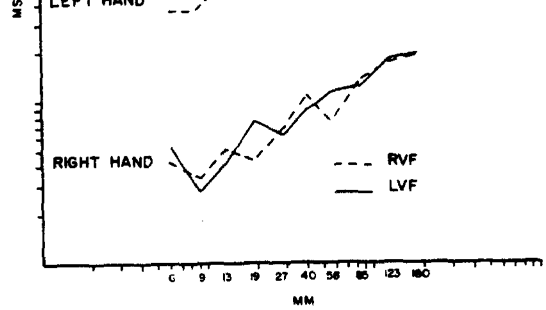

FIG. 6. Geometric mean duration (CMM) judgments (ordinate) by left (upper plot) and right (lower plot) hands of line length stimuli (abscissa) presented to right (RVF) and left (LVF) visual fields of non-visually split patients. RH and LH designate responding by the right and left hands, respectively.

Table 3. Reading

Subject	Stimulus	Response	% Correct with responding hand: Right hand	Left hand	Combined
P.S.	Visual word	Point to 1 of 4 pictures	RVF: 83	100	92
			LVF: 75	83	79
J.H.	Visual word	Point to 1 of 4 pictures	RVF: 100	83	91.5
			LVF: 33	17	25
			% Correct with responding hands combined		
D.H.	Tactile word	Point to 1 of 10 letters	RH: 75		LH: 7
		Point to lower case form	RH: 100		LH: 0
J.Kn.	Tactile letter	Point to 1 of 10 letters	RH: 80		LH: 0

DISCUSSION

Results of the present study demonstrate that the separated hemicortices of commissurotomized Ss do not scale univariate stimuli asymmetrically. This finding bears on several areas of investigation.

Verbal–numerical mediation of CMM

KRANTZ ([6]; see also [3]) has hypothesized that in a CMM task first a number is assigned which is proportional to stimulus magnitude and then the CMM is made to the number assigned. This hypothesis is inconsistent with the present data which indicate that reading and calculation are severely limited in the right hemispheres of all but one of these Ss. The ability of these Ss to make similar and meaningful CMM judgments of lateralized stimuli in both hemispheres, regardless of differing verbal and numerical abilities in the right hemisphere, combined with their ability to make ME judgments in the right hemisphere, is evidence that CMM is not mediated by any sub-vocal numerical assignment whose use can be measured in reading and calculation abilities. That CMM and ME are independent judgments makes the predictability of CMM results from ME results, and vice versa, across tasks and often across groups, an important argument in favor of the validity of these direct scaling methods, and helps to refute the long standing philosophical arguments against the possibility of the judgment of sensation.

One reviewer suggested the possibility that CMM could occur by subvocal proportional number assignment independently of the reading and calculating abilities we tested. The postulated ability of the separated right hemisphere to generate numbers proportional to stimulus magnitude in the absence of any consistent ability to use numbers cannot be ruled out. However, this postulation is less a testable hypothesis and more a philosophical question concerning the meaning of number assignment. Such assignment would be unobservable and inconsistent with the subjects' inability to manipulate numbers in the right hemisphere. Further, there is anecdotal evidence against such a view. Patient P.S., who often exhibited signs of conflict such as head shaking when giving meaningless verbal answers to stimuli confined and correctly responded to by the right hemisphere, did not do so in the ME task.

Table 4. Calculation

Subject	Task	Response Order Visual	ERr	RVF accuracy (%)	Correct Verbal Report (%)	ERl	LVF accuracy (%)	Correct Verbal Report (%)
P.S.	Add	Report first	0	100	100	2	60	0
		Point first	na	80	100	na	100	40
	Subt.	Report first	0	100	100	2	33	0
		Point first	na	80	100	na	60	0
	Mult.	Report first	0	90	100	2	49	0
		Point first	na	100	100	na	60	40
		Point first (choose problem)	1	67	67	1	0	0
	Div.	Report first (choose problem)	0	67	100	1	33	0

Subject	Task	Presentation Point first	Right hand (%)	Left hand (%)	Correct Report RH (%)	Correct Report LH (%)
P.S.	Add	Tactile	80	41	80	0
	Subt.	Tactile	75	25	100	0
	Mult.	Tactile	88	69	88	6
	Div.	Tactile	92	25	92	0
J.H.	Add	Visual	RVF: 100	LVF: 0		
	Mult.	Visual	RVF: 100	LVF: 0		
	Add Numbers	Tactile	80	40		
	Add Marbles	Tactile	100	100		
			Point to number of marbles in each hand			
D.H.	Add	Tactile	83	0		
			Intramanual match with marbles			
			80	0		
J.Kn.	Add	Tactile	Intermanual match with marbles			
			SRRL	SLRR		
			50%	10%		
			Intramanual match with marbles			
			57%	9%		

ERr = responded to own erroneous verbal report of RVF stimulus.
ERl = responded to own erroneous verbal report of LVF stimulus.
SRRL = stimulate right hand, responds with left hand.
SLRR = stimulate left hand, responds with right hand.

Presumably if the right hemisphere had generated a number not in agreement with that reported by the left hemisphere, such conflict by cross-cuing [37] would arise. The fact that it did not suggests that the right hemisphere had not generated a number as such.

It should be noted that for these patients, the exponents of CMM and ME judgments were generally not in close agreement with group exponents reported in the literature. The authors suspect that this result is due to the small number of subjects and their lack of numerical sophistication rather than to real differences in sensory transduction. Although single subject data under some circumstances approximates the power function obtained from grouped data (e.g., [40]), often such data are not well described by it when other than graduate students are Ss [41]. Moreover, consistent individual differences in exponents have been reported [42, 43].

Perceptual asymmetries

There was no evidence for asymmetrical processing of psychophysical scaling by each separated hemisphere. This report stands at variance with reports of asymmetrical processing of similar univariate stimuli.

A. Visual. The absence of significant asymmetries in CMM scaling of lateralized line length stimuli contrasts with the literature summarized earlier reporting preferential right hemisphere processing of univariate visual stimuli which are comparable to those used in the present study. However, even within that literature discrepancies exist. The LVF–right hemisphere superiority on a dot localization task reported by KIMURA and DURNFORD [7] has not been found by others [44–46] even when correction is made for detection accuracy [47]. Similarly, while some studies suggest right hemisphere mediated same–different discrimination of certain univariate stimuli including line length [7, 14, 15], even within the same study stimuli comparable to line length do not produce hemispheric differences [15]. Although inconsistencies exist and often the reported differences are small, this literature is generally discrepant with the present results. Also, the one difference sufficiently robust to survive a conservative statistical criterion [15], was elicited by line length, which commissurotomized subjects in the present study scaled symmetrically.

Traditionally, the presence of "spatial" stimulus properties has been postulated to underly a right hemisphere advantage [11, 28, 48]. Thus, while the dot localization and same–different matching tasks of line orientation and gap size involve stimuli that are univariate, nevertheless it could be argued that appreciation of the stimulus within a frame of reference, i.e., spatial processing, is required. This view is supported by a positive correlation between performance of right but not left hemisphere lesioned patients on same–different "perceptual matching" tasks of univariate stimuli and the patients' performance on tasks of cube analysis and block design [14]. Since the latter two tasks are generally considered to have strong spatial components, this association suggests that a common ability is tested in all these tasks. In contrast, simple detection tasks which require no spatial context are performed with equal facility by each hemisphere [9, 14, 47]. In this way, the discrepancy between the present results and the reports of a right hemisphere advantage may be accounted for simply by asserting the presence or absence of spatial properties, i.e., if the right hemisphere is implicated in a given task, the stimuli have spatial properties perforce.

However, relegating tasks preferentially handled by the right hemisphere to the category of spatial explains neither the absence of asymmetries in the present study nor the presence of asymmetries in studies which require only comparison between the stimuli themselves without reference to a spatial context [9, 10, 14, 15]. Nor can the putative presence or absence of spatial stimulus properties explain the stronger McCollough hue to test grids in the LVF of normals [21] or more accurate depth perception by the right hemisphere [16–18]. Thus it may be that task, rather than stimulus, variables are instrumental in engaging the right hemisphere when more than simple stimulus detection, but not necessarily spatial, processing is required.

B. Tactile. The consistency in the present study of tactile judgment between the hands is not in accord with either SEMMES' data [22] or her formulation [24]. Moreover, this discrepancy in results holds whether the joint position task is viewed as requiring spatial appreciation which is best processed in the right hemisphere, or requiring close matching of input and output, consonant with left hemisphere functioning. However, there is agreement between the exponents obtained in the present study, and findings that single unit discharge in the monkey ventrobasal thalamus varies as a monotonic function of joint position which is best described by a power function with an exponent between 0.5 and 0.6 [49]. This is comparable to the exponents obtained in the present study under CMM response conditions by Ss able to transfer tactual information.

STEVENS and STONE [50] obtained a value of 1.3 from normal Ss verbally judging thumb and middle finger joint position. This is larger than the exponents of 0.63 to 0.74 obtained in the present study by the right hand under ME conditions. Any differences between exponents which describe thalamic and behavioral responses to stimulus magnitude may indicate a non-linear transformation above the level of the thalamus. Since in the present study, each hemisphere produced exponents which were not significantly different, it can be concluded that if the cortex exerts extra-thalamic non-linear transformations on joint position information, it does so symmetrically.

C. Conclusions. The emergence of perceptual asymmetries may depend on the necessity for a comparison of stimulus attributes. In same–different matching tasks, the stimulus information must be processed in the context of previously appearing or concurrent but spatially separate stimuli. Similarly, both depth perception [18], based on visual disparity cues, and long term after-effects like the MCCOLLOUGH effect [21] are processed asymmetrically, and may also be viewed as arising from the comparative processing of visual stimuli separated by time or space. Stereopsis emerges from the perception of concurrent and potentially rivalrous stimuli imaged at disparate retinal locations in the two eyes, and some visual after-effects appear after prolonged exposure to complementary adapting stimuli (e.g., [19]). This is in contrast to symmetrically processed tasks of stimulus detection [9, 47] and to the line length and joint position scaling tasks in the present study, in which the S makes a sensory–sensory match in responding. In these latter tasks no comparison between stimuli is required. Thus, there may be some reliance on the right hemisphere when stimulus comparisons are required. If so, this was not engaged in the present study, which required a direct sensory match. Whatever the bases of lateralized right hemisphere processing, such ability was not engaged in the present study, and the separated hemispheres did not scale stimuli in any substantially different way. By extension, whatever hemispheric differences exist occur beyond the processing levels of stimulus detection or scaling.

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Résumé

On a cherché à répondre à 2 questions concernant la médiation d'une échelle psychophysique pour les stimulus latéralisés chez les sujets commissurotomisés: (1) l'appariement intermodal est-il réalisé par une désignation numérique subvocale? (2) les différences hémisphériques existent-elles dans la réalisation de l'échelle psychophysique? Lorsqu'on compare les exposants des fonctions de puissance, caractérisant l'estimation de grandeur de la position de l'articulation dans les mains droite et gauche et la longueur des lignes dans le champ droit et le champ gauche, l'hémisphère gauche est le seul capable de faire de tels jugements. Quand les exposants des fonctions caractérisant l'appariement intermodal de ces stimulus étaient comparés selon chaque hémisphère, il n'y avait pas de différence significative. Ces résultats ne sont pas en faveur d'une médiation de l'appariement intermodal par une désignation numérique subvocale et cette démonstration de transduction des stimulus univariés impose réinterpréter la littérature sur les asymétries perceptives.

Zusammenfassung

Zwei Fragen, welche die Vermittlung psycho-physischer Skalierung lateralisierter Stimuli betreffen, wurden bei Patienten mit Kommissurotomie untersucht: 1. wird die Zuordnung über Modalitäten hinweg durch subvokales Numerieren vermittelt? 2. Gibt es hemisphärische Unterschiede in der psycho-physischen Skalierung? Wenn die Größe der Gütefunktion für die Einschätzung des Ausmaßes der Gelenkposition an der rechten und linken Hand und der Länge von Linien im rechten und linken Gesichtsfeld zwischen den Hemisphären verglichen wurde, war nur die linke Hemisphäre imstande, derartige Urteile abzugeben. Wenn die Größe der Gütefunktionen für die Zuordnung dieser Stimuli über die Modalitäten hinweg zwischen den Hemisphären verglichen wurde, fanden sich keine signifikanten Unterschiede. Diese Ergebnisse sprechen dagegen, daß das kreuzmodale Zuordnen über ein subvokales Numerieren der Stimuli vermittelt wird, und dieser Nachweis einer symmetrischen Überleitung univariater Stimuli legt eine neue Interpretation der Literatur über Asymmetrien der Wahrnehmung nahe.