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COMPLEMENTARITY OF CEREBRAL FUNCTION

M.P. Bryden

and

M.B. Bulman-Fleming

University of Waterloo
Waterloo, Ontario
Canada

It has become an accepted item of public awareness that language functions are represented in the left hemisphere and nonverbal functions in the right hemisphere. Admittedly, there are a few exceptions, because we know that a rather high percentage of left-handers have speech represented in the right hemisphere. The recieved view is that this complementary specialization exists becuase neurobiological development leads grossly differing functions to lateralize to opposite hemispheres. By this model, which I shall term causal complementarity, the right hemisphere is involved in visuospatial and other nonverbal functions because the left hemisphere has been pre-empted by language processes. By implication, if we find an individual with right-hemisphere language, then that person should manifest left-hemisphere specialization for nonverbal functions. The prediction from such a model is that there should be a strong negative correlation between measures of verbal functional asymmetry and measures of nonverbal functional asymmetry. That is, if we measure language lateralization by some procedure such as a verbal dichotic listening task or a visual hemifield task, and score it in such a way that positive values indicate a right ear or right visual field advantage, and nonverbal lateralization by an nonverbal dichotic task or a spatial visual hemifield task, and score it in the same we, we will find that most people will have positibe scores, indicative of left hemispheric superiority, on the verbal task, and negative scores, indicative of right hemispheric superiority, on the nonverbal task. By the argument of causal complementarity, those few people who show negative scores --- right hemisphere superiority --- on the verbal task will also show positive scores --- left hemisphere superiority --- on the nonverbal task. This will result in a negative correlation between verbal and nonverbal tsks. **SLIDE 1**

An alternative view which I have often espoused is that the causal nature of complementary specialization is illusory. If the vast majority of people are left-hemispheric for language, and likewise the vast majority are right-hemispheric for nonverbal functions, then most people will manifest complementary specialization on a simple statistical basis, and it will appear that the complementarity is causal. This can be seen in **SLIDE 2,** where I have used the same marginal totals as in the first slide. I have called this effect statistical complementarity. Such a model predicts that there should be a zero correlation between measures of verbal functional asymmetry and measures of nonverbal functional asymmetry.

A third possibility is that there are no real deviations from the species norm of left-hemisphere verbal functions and right-hemisphere nonverbal function other than those consequent upon relatively major early brain damage. However, because of asymmetries in the ascending sensory systems, there are individual differences in an overall bias to one side or the other within each sensory modality. Thus, people who have a bias to the right will manifest a large right-ear advantage, reflecting left-hemisphere superiority, on a verbal dichotic task but may also show a smaller right-ear advantage on a nonverbal task. Similarly, people who have a bias to the left may actually produce a left-ear advantage on the verbal dichotic task, but will manifest a large left-ear effect on the nonverbal task. There will, however, be no people with "reversed" lateralization. **SLIDE 3** Such a view has been put forth by Efron, Yund, and Nichols (1985), by Sidtis (1980), and by Teng (1980). This model would lead to a large positive correlation between measures of verbal functional asymmetry and measures of nonverbal functional asymmetry. I will refer to this as a bias model. Although the conceptual mechanism may

Conjecture

be somewhat different, the position that there are large individual differences in attentional bias (Kinsbourne, 1975) or hemisphericity (Torrance, 1977) leads to the same prediction.

Initially, I had two reasons for believing that statistical complementarity might be the best description of the data. First, the literature suggested that there was at least a modest relation between handedness and the prevalence of aphasia following left-hemisphere damage. On the other hand, handedness did not seem to be particularly important in predicting right-hemisphere effects such as neglect, visuospatial disorder, or prosopagnosia. If handedness were related to left- and right-hemisphere functions differently, then it followed that functions subserved by the two hemispheres could not be causally linked.

Secondly, I had done a large number of studies concerned with perceptual asymmetries in normal subjects, primarily dichotic-listening studies and visual half-field studies. In this work, robust right-visual-field and right-ear effects were easy to obtain with verbal material. In contrast, right-hemisphere effects were small and often difficult to find. Granted, some of this may have been because of the difficulty of making a task truly nonverbal, but it did suggest that right-hemisphere functions were lateralized in a different way than were left hemisphere functions. Again, if this were the case, it would be hard to argue for causal complementarity.

A breakthrough of sorts occurred in the early 1980's, when Henri Hécaen provided me with the data on a large number of cases with unilateral brain damage, in which each individual was classified as aphasic or not aphasic and also as visuospatially impaired or not. These data permitted me to estimate the association between language disorders and visuospatial disorders for right-handers and left-handers separately: the relevant data for right-handers are shown in **SLIDE 4** . Here, the two variables are unrelated, although language disturbances most often follow upon left-hemisphere damage and visuospatial disturbances follow upon right-hemisphere damage. The comparable figures for left-handers are shown in **SLIDE 5**. Here the two variables are positively associated. Recall that the complementary specialization argument calls for a negative correlation. Although a positive correlation might be taken as support for the bias model, it can also arise in this data set because some functions are bilaterally represented in left-handers, with the result that damage to either hemisphere leads to a deficit. Because this study involved patients with unilateral brain damage, we don't know what would have happened had the damage been to the opposite hemisphere.

Looking for evidence for a negative correlation between left- and right-hemisphere functions in normal subjects is not an easy task. Few researchers administer both verbal and nonverbal tasks to the same subjects, and of those who do, few report the data in a way that one can determine the association between the two. Recently, one of our students, Jim Nikelski, put together the data from those studies he was able to find that presented the appropriate data and we were able to add several others from our files. Sadly, we were able to find only a dozen or so studies in which the same subjects were given tasks that tapped both left- and right-hemisphere functions and in which the data were reported in a form that allowed us to classify the subjects. **SLIDE 6?**

We entered these data into a log-linear analysis, with hemisphere advantage for the Verbal task (L or R), hemisphere advantage for the Nonverbal task (L or R), and Study as primary factors. This analysis revealed an insignificant Verbal by Nonverbal interaction ($\chi^2 = 2.07$, 1 df), providing little evidence to support the idea of a truly complementary specialization that can be observed across tasks. Unfortunately, there was also a very large Study by Verbal by Nonverbal interaction, indicating that different effects occurred in different studies ($\chi^2 = 24.80$, 12 df, $p = .015$). An examination of the data revealed two fairly large studies with significant Verbal-Nonverbal interaction effects, with opposite effects. When these studies were removed from the analysis, leaving us with 11 studies, neither the Verbal-Nonverbal interaction ($\chi^2 = 1.25$, 1 df, $p > .4$) nor the Study by Verbal-Nonverbal interaction ($\chi^2 = 9.43$, 10 df, $p > .4$) even approached significance, and the largest remaining z-value was 1.47.

One of the two studies with significant effects was Mirna Vrbancic's doctoral dissertation study (Vrbancic, 1989; $z = 3.16$, $p < .001$). In this study, subjects were given two different dichotic tasks, one involving the identification of CV-syllables (pa, da, ga), and the other involving the perception of dichotically presented two-tone sequences. Laterality effects on these two tasks proved to be positively correlated (r = .xxx, df = 190, $p < .001$) , although the verbal task produced an overall REA and the tones task an overall LEA. Individuals with an REA for tones also showed a larger REA for syllables, whereas those with an LEA for syllables produced a larger LEA for tones. Rather than supporting the notion of complementarity, such a positive correlation could be taken as evidence for individual differences in attentional bias (Mondor & Bryden, 1993), or as indicating some kind of subcortical asymmetry that affects verbal and nonverbal material alike. Such proposals have been offered.?? **(or did you have more to say here?)**

The other deviant data come from our own recent work on the lateralization of affect (Bulman-Fleming & Bryden, 1994, $z = 2.00$, $p < .05$). In these studies, subjects listened to the words "bower, dower, tower, and power", spoken dichotically in happy, angry, sad, or neutral tones of voice. For each dichotic pair, the two items differed in both word and tone of voice. Subjects were given a specific target, such as "angry bower" and instructed to signal every trial on which this target occurred. There were thus 5 different types of trials. **SLIDE 7** On some trials, the target actually was present at one ear. On other trials, the target word was presented to one ear but not in the appropriate tone of voice, while the target affect appeared at the other ear carried by a different word. On some trials, the target word was present but not the target affect, and on others the target affect was present but not the target word. Finally, there were trials on which neither component of the target appeared at either ear.

We looked primarily at the false alarms --- those trials on which the subject claimed to have heard the target but when it was not actually presented. Such false alarms were far more likely when the target word, spoken in a different affect, appeared at the right ear than when it appeared at the left ear. Similarly, false alarms were much more common when the target affect appeared at the left ear carried by some other word than when the target affect appeared at the right ear. When the target affect appeared at one ear and the target word at the other ear, false alarms were far more common when it was the word at the right ear than when it was the affect at the right ear. Thus, this procedure can reveal both a right-ear (left-hemisphere) advantage for verbal material and a left-ear (right-hemisphere) advantage for affect at the same time, as a within-trial effect. **SLIDE 8** Over the past several years we have carried out a number of experiments using this procedure, testing both left- and right-handed subjects of both sexs. When the data from these studies are aggregated, there is a negative association between verbal and nonverbal effects that reaches the .05 level of significance--- in other words, at least modest evidence for true complementarity.

almost

In virtually all of the studies we reviewed, the subjects were tested on two quite discrete tasks. In the majority of such studies of this type, there was simply no relation between verbal laterality and nonverbal laterality. In the Vrbancic study, the two were positively correlated. The problem with such a procedure is that it allows individuals to develop an appropriate strategy for dealing with the verbal task, and a potentially different strategy for dealing with the nonverbal task. To the extent that this is true, the only proper assessment of complementarity comes from our bower/dower studies, in which both verbal and nonverbal effects are assessed simultaneously. Because these studies do reveal a significant, albeit small, negative association between verbal and nonverbal functions, they provide limited support for the notion of complementary specialization.

However, the negative association in our affect studies is relatively small, and it is possible that a hybrid of causal complementarity and random determination of hemispheric specializations may be the most plausible case. By this argument, some proportion (X) of people develop in such a way that language is lateralized to one hemisphere and nonverbal functions to the other and in the remaining Y individuals, the mechanism that leads to this standard lateralization is turned off, and functional asymmetries develop by chance. A model of this general form has been developed by McManus (1985) to account for the relation between handedness and language lateralization. In the McManus model, about 80% of the population are both right-handed and left-hemispheric for language because of their genotype; in the remaining 20% of the population, handedness and language lateralization are randomly determined by fluctuating asymmetry (which can be thought of as minor, non-directional deviations from bilateral symmetry).

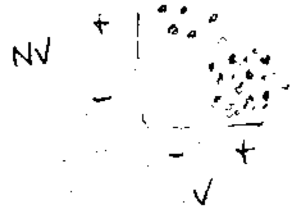
One can make a similar argument about the relationship between left- and right-hemisphere functions. **SLIDE 9** shows how the log odds ratio relating verbal to nonverbal function changes as a function of the proportion of people whose lateralization is determined at random. So, here we are dealing with the ratio of two odds: the odds of having nonverbal abilities located primarily in the right hemisphere given left-hemisphere language, and the odds of these abilities being subserved by the left hemisphere given left-hemisphere language. If complementarity were truly causal in the vast majority of individuals, the odds ratio would be very high; if complementarity were merely statistical for the majority, the odds ratio would be near zero. The figure shows how this value would change with an increasing proportion of "type X" (the causal complementarity) people. It also shows where the Bulman-Fleming and Bryden (1994) data fit on this curve. The odds ratio in our data is such that it is best fit if 25% of the population manifests causal complementarity and 75% shows random determination of the lateralization of left- and right-hemisphere functions. Of course, error of measurement problems will lead to the observed odds ratio being an underestimate of the real value. Because measurement error introduces a random factor into the data, the proportion of people showing causal complementarity should be increased by the measurement error --- perhaps to 40-50%. Nevertheless, this implies that lateralization is randomly determined in a large proportion of the population, at least within the auditory domain.

Causal Complementary Specialization

Verbal

Nonverbal	Left	Right	Total
Left	0	10	10
Right	90	0	90
Total	90	10	100

A NEGATIVE correlation



Statistical Complementary Specialization

	Verbal		
Nonverbal	**Left**	**Right**	**Total**
Left	**9** a	**1** c	**10**
Right	**81** b	**9** d	**90**
Total	**90**	**10**	**100**

A ZERO correlation

$\frac{9\times 9}{81\times 1} = 1$

$\frac{81/9}{1/9} \rightarrow \frac{9}{1/9} = 81$

$\frac{b/a}{d/c}$

$\frac{b}{a} \cdot \frac{c}{d}$

$\frac{b}{a} \cdot \frac{c}{d}$

Biased Complementary Specialization

	Verbal		
Nonverbal	**Left**	**Right**	**Total**
Left	**10**	**0**	**10**
Right	**80**	**10**	**90**
Total	**90**	**10**	**100**

A POSITIVE correlation

$\frac{10 \times 10}{90 \times 0} \Rightarrow \infty$

$\frac{80/10}{1/10} \Rightarrow \frac{8}{.1} \Rightarrow 80$

(4)

RIGHT-HANDED

		Spatial Dysfunction	No Spatial Dysfunction		
L Hemi	Aphasic	9	27	36	$\frac{9\times 27}{27\times 7} \doteqdot 1$
	Not Aphasic	7	27	34	
		16	54	$X^2 = 0.19$	
R Hemi	Aphasic	3	2	5	$\frac{3\times 27}{27\times 2} \doteqdot 1$
	Not Aphasic	28	27	55	
		31	29	$X^2 = 0.15$	

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LEFT-HANDED

		Spatial Dysfunction	No Spatial Dysfunction		
L Hemi	Aphasic	34	32	66	$\frac{34 \times 16}{32 \times 5} \simeq 3$
	Not Aphasic	5	16	21	
		39	48	$X^2 = 4.94$	
R Hemi	Aphasic	12	5	17	$\frac{12 \times 19}{5 \times 17} \simeq 2$
	Not Aphasic	17	19	36	
		29	24	$X^2 = 2.54$	

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Verbal - Nonverbal Associations

Study	N	Log OR	Z
McGlone & Davidson (1975)	66	-0.84	-1.52
Sidtis (1982)	28	2.25	1.47
Ley & Bryden (1982)	31	0.89	0.57
Murray (1985) - S1	24	-0.15	-0.13
Murray (1985) - S2	24	1.13	1.10
Segalowitz (1985)	16	1.20	0.74
Bryden (1986)	120	0.42	1.02
Alter et al. (1989)	26	0.39	0.50
Kim & Levine (1991)	58	0.56	0.89
Vrbancic (1989) - vis	118	0.07	0.17
Vrbancic (1989) - aud	108	1.64	3.16**
Bulman-Fleming & Bryden (1996)	107	-0.81	2.00*

(7)

Bulman-Fleming & Bryden
Procedure

Stimuli

Bower, Dower, Tower, Power
spoken
Happily, Sadly, Angrily, Neutrally
(N = 16 possible targets)

Paired dichotically, so that the two items differ in both word and tone of voice.

Task

circle Say "yes" to a specific target
e.g. "Dower" spoken sadly
circle Say "no" otherwise

Look at

False alarms: "yes" when the specific target was not present.

Bulman-Fleming & Bryden

"Yes" response is correct:

Target present at one ear.

"No" response is correct:

Type 1

Target word is present, but target affect is not.

Type 2:

Target affect is present, but target word is not.

Type 3:

Both target word and target affect are present, but at opposite ears.

Type 4:

Neither target word nor target affect is present.

Bulman-Fleming & Bryden
Results

Sometimes the target word is present, but not spoken in the correct tone of voice.

More false alarms when word is at right ear than when it is at left ear (left-hemisphere effect).

Sometimes the target affect is present, but not carried by the correct word.

More false alarms when affect is at left ear than when it is at right ear (right-hemisphere effect).

Sometimes both the target word and the target affect are present, but at opposite ears.

More false alarms (illusory conjunctions)when target affect is at left ear and word at the right ear than when the opposite is true.