Matters arising

Ideomotor apraxia: evidence for the preservation of axial commands

Sir: In an earlier issue of this journal Poeck, Lehmkuhl and Willmes¹ reported an experiment designed to test the claim by Geschwind^{2,3} that in cases of ideomotor apraxia a certain class of movements, which he termed *axial*, are selectively spared. These are movements of the eyes, neck, and trunk that in his view can be executed independently of the primary (pyramidal) motor system. Geschwind maintained that these movements are better performed to verbal command than are movements executed by the primary system, such as contralateral movements of the digits and limbs or movements of the cranial musculature exclusive of the eyes. The explanation he proposed is that the verbal command for a limb or buccofacial movement is first processed in Wernicke's area and then transmitted forward to the primary motor area for execution. Such commands are therefore vulnerable to lesions that disconnect Wernicke's area from the primary motor area. Axial commands, however, are not affected because they do not require the transcortical link to the primary system. The clinical phenomenon of axial sparing is thus a crucial point in Geschwind's disconnection theory of apraxia.

Poeck *et al.* however, found no evidence for axial sparing in their experiment, calling into question some fundamental assumptions of Geschwind's theory. Their experiment is an important one because it not only provides the first controlled test of the axial-sparing hypothesis, but is also the first investigation of apraxia to employ a multifactorial experimental design with the attendant increase in statistical precision. They tested both axial movements and movements of the arm, leg, and buccofacial musculature on 60 aphasic patients, divided equally among cases of Global, Wernicke, Broca, and Amnesic aphasia. All movements were tested separately to verbal command and to imitation. The results are presented for all conditions of the experiment, although the authors limited their analysis and discussion to the single question of axial sparing.

Their negative conclusion is based on nonparametric statistical tests (Wilcoxon, Friedman). The results of those tests are not reported in detail but only in the form of the following summary statement (p. 1117): "The main finding was that there was no significant difference in the performance of

axial and buccofacial movements. Both types of movements did not significantly differ from unilateral limb (arm or leg) movements. The only exception found was for global aphasia in the verbal mode of testing." In their final paragraph the authors restate the conclusion unequivocally (p. 1128): "Our findings demonstrate that axial movements are not, as a rule, preserved in patients with ideomotor apraxia. If certain types of movement are impaired in some patients to a different degree, this only reflects the variability of performance which is common to any neuropsychological syndrome."

That conclusion, however, does not seem to be consistent with the detailed data reported in their tables. As the statistical analysis is not fully described, and non-parametric tests are particularly liable to error, I applied a simple parametric test to the data of the tables as a check, and found that the effect of axial sparing is consistently significant in all four clinical groups. This conclusion was subsequently confirmed by several other standard statistical procedures.

In view of the clinical and theoretical importance of the question I report here the results of those tests. They establish the existence of axial sparing beyond any reasonable doubt. The corrected statistical analysis also brings out several features of apraxia and axial sparing that were not evident from earlier investigations. These findings, and their implications for the theory of Geschwind, will be discussed after the statistical evidence has been reviewed.

Experimental data: movements to verbal command

The data relevant to axial sparing are reported by Poeck *et al.* in their table 4. That table gives the mean, median, standard deviation, maximum, and minimum for each combination of the three experimental variables (patient group, type of movement, mode of presentation). To bring out the main effects the fig presents the results for movements to verbal command in graphical form. Each bar represents the proportion of correct responses for arm, leg, oral,* or axial movements. These values were obtained by dividing the mean scores given in their table by the number of items in each subtest. The various sets of bars give the results for the

four clinical groups and the averages for all 60 patients (left-hand set). The data for imitation are not included, as they are not directly related to the issue of axial sparing.

It can be seen from the fig that axial commands (black bars) were performed considerably better than any of the other commands by all four groups. The probability of that outcome on the null hypothesis that the type of command has no effect on performance is $1/4^4 = 0.004$. That in itself is sufficient reason for reconsidering the authors' negative conclusion. Taken over all 60 patients the mean error rate for axial commands is only 25.4%, compared with 43.7% for non-axial commands, a difference of nearly 2 to 1. By contrast, the overall error rates for the three non-axial types of command are almost identical ($\pm 1\%$). To inspection, then, the data are in good agreement with Geschwind's assertion that axial commands are selectively spared.

Statistical analysis

In order to disprove the negative conclusion of Poeck *et al.* it is not necessary to compute exact test statistics but only to establish that they must be greater than some lower bound which is itself significant. For standard parametric tests like *t* and *F* lower bounds can be computed from the published means and standard deviations without recourse to individual scores. The method is explained here for the simpler case of the *t* test.

Consider a *t* test between the mean scores for axial vs oral commands in the Amnesic group (the two right-hand bars in the fig). As the observations are paired (both types of command were given to the same patients), *t* would normally be computed from the differences between the two scores for each of the $n = 15$ patients by the formula

$$t = \frac{\bar{d} \sqrt{n}}{s_{\text{diff}}}, \quad f = n - 1, \quad (1)$$

where $\bar{d}$ is the mean of the differences and s_{diff} their standard deviation. But *t* also can be computed directly from the two sets of scores, since

$$\bar{d} = m_1 - m_2, \quad s_{\text{diff}} = \sqrt{s_1^2 + s_2^2 - 2rs_1s_2}, \quad (2)$$

where m_1 and m_2 are respectively the mean scores for axial and oral commands, s_1 and s_2 the corresponding standard deviations, and *r* the coefficient of correlation between the two sets of scores. All of these data except *r* are supplied by Poeck *et al.* in their table 4.

When the observations are paired, as in this instance, the correlation *r* is expected to be positive. That is the statistical advantage

*In their tables Poeck *et al.* use the term *oral* in place of *buccofacial*. In referencing their data I follow that usage here. Apraxia for oral movements, in this terminology, should not be confused with the term *oral apraxia* used by many writers to signify motor disorders on speech production.

Fig Mean proportion of movements performed correctly to verbal command for the four patient groups studied by Poeck *et al.*¹ The different types of movement are designated by the letters A (arm), L (leg), O (oral), and X (axial).

of using paired observations, since a positive r reduces s_{diff} (Eq. 2) and thereby increases the value of t . By computing t on the assumption that $r = 0$ we therefore obtain a lower bound on the true value. In effect, we are assuming that there are no individual differences between subjects. A bias is thereby introduced into the test, but the bias acts *against* detection of a significant axial sparing effect and *in favour* of the null hypothesis. If the test result computed on the assumption of zero correlation is significant, we then know that the value of t computed from individual scores must also be significant.

Returning to the example, the mean percentages of correct responses for axial and oral commands in the Amnestic group are 90.2% and 74.7%, and their standard deviations are 9.8% and 16.4% respectively. Substituting these values in the above formulas, and setting $r = 0$, we obtain $t(14) = 3.14$, $p = 0.0036$. The value of t computed from individual scores must therefore be at least this large, and consequently is significant at the 0.005 level.

The correlation between paired scores is generally quite large for groups of aphasic patients. Values of r between +0.60 and +0.90 are typical for data of this kind. Poeck *et al.* (p. 1126) specifically remark that individual differences in severity were prominent within each group. As a conservative estimate of the correlation for their data we may take $r = +0.50$, the correlation just significantly different from zero at the 0.05 level. On this assumption we get $t = 4.21$, $p = 0.0004$. The superiority of axial over oral commands for the Amnestic group is thus statistically demonstrable.

Table (A) gives the lower bounds on t ,

computed as above, for each of the 12 possible comparisons between axial and non-axial commands. All are significant at least at the 0.05 level (single asterisks), and 7 of the 12 at the 0.01 level (superscript 7); the median level of significance is $p = 0.008$. These lower bounds are sufficient to establish the main point that axial sparing is statistically significant. If the conservative degree of correlation between scores is assumed ($r = +0.50$), then all 12 t tests of axial vs. non-axial commands become significant at least at the 0.01 level, and half exceed the 0.001 level.

As a control, the differences between the means for the three types of non-axial commands were tested in the same way. The results are shown in the table (B). None of the 12 lower bounds on t for these comparisons reaches significance at the 0.05 level. (Significance levels are for one-tail tests with absolute values of t to make them comparable with those in table (A).) On the

assumption that $r = +0.50$, 1 of the 12 tests reaches the 0.05 level, a result consistent with the null hypothesis for the number of tests.

Multiple t tests do not give the most powerful test of axial sparing but are used here because the lower bound condition is easily defined. As the calculations are simple, this type of analysis is useful as a handy method of checking the computation of other tests. The t test is particularly suited to this purpose because it is extremely robust. Numerous studies have shown that its operating characteristics are not materially affected either by departures from normality or by inhomogeneity of variance.⁴⁻⁶

Two tests of greater power, analysis of variance and loglinear analysis, were used to confirm the result of the t tests. The former gives lower bounds for F analogous to those for t , based again on the assumption that there are no individual differences between subjects. The differences between types of movement give the lower bound $F(3,168) = 11.7$, $p < 0.0001$. Group differences are also significant at that level, but the group X movement interaction is negligible, $F(9,168) = 0.52$. Loglinear analysis,⁷ although less familiar, is perhaps the statistical method of choice as it assumes discrete frequency data of the kind reported by Poeck *et al.* The test of axial sparing here gives $X^2(3) = 88.4$, $p < 10^{-10}$. By contrast, the three non-axial types of movement do not differ among themselves, $X^2(2) = 0.87$, $p > 0.50$. Group differences are also highly significant, but the group X movement interaction is not, $X^2(9) = 8.82$, $p > 0.40$. These multidimensional tests show that axial sparing has a high order of statistical significance in these data.

Contrary to the conclusion stated by Poeck *et al.*, their experiment actually provides the most systematic quantitative

Table Lower bounds on t for performance to verbal command

A. Axial vs. Non-axial movements

Group	Axial v. Arm	Axial v. Leg	Axial v. Oral
Global	3.43†	2.63†	2.99†
Wernicke	1.89*	1.89*	1.94*
Broca	1.82*	2.34*	3.38†
Amnestic	2.92†	3.28†	3.14†

B. Non-Axial vs. Non-Axial Movements

Group	Arm v. Oral	Leg v. Oral	Leg v. Arm
Global	-0.38	0.55	0.96
Wernicke	-0.68	-0.36	0.37
Broca	1.48	1.08	-0.44
Amnestic	0.35	0.00	-0.36

* $p < 0.05$. † $p < 0.01$.

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evidence for axial sparing that has yet appeared. The effect is apparent from the bar graphs of the fig, and standard parametric tests establish its significance statistically. The merits of the experiment should not be obscured by the mistaken conclusion, however, for the results are of interest not only as proof of axial sparing but for their bearing on other issues concerning apraxia.

From a clinical point of view, the magnitude of the axial sparing effect is as important as its statistical significance. The data of Poeck *et al* give the first quantitative estimates of the size of the effect. On the average, aphasic patients make 83% more errors on non-axial commands than they do on axial commands. The increase is 52% for Global, 70% for Wernicke, 93% for Broca, and 116% for Amnesic patients. Axial sparing is thus a major feature of apraxia in all four forms of aphasia.

These percentage increases are directly proportional to the percentage of correct responses for each group. The non-significant interaction term in the multivariate tests establishes statistically that the size of the axial sparing effect is independent of the specific form of aphasia. This is an important finding, for it indicates that axial sparing is an inherent feature of ideomotor apraxia, not an occasional or ancillary phenomenon. Theories of the neural mechanism responsible for apraxia therefore need to explain not only why axial sparing occurs, but why it appears uniformly in different forms of aphasia.

Apart from its implications for axial sparing the study of Poeck *et al* challenges two current beliefs about ideomotor apraxia. In nonfluent forms of aphasia (Broca, Global) buccofacial apraxia is generally thought to be more severe than limb apraxia.^{8,9} In the present analysis, however, they are not significantly different. In the individual case, of course, buccofacial or limb apraxia may occur in isolation; but the data indicate that such differences average out over a series of patients with the same form of aphasia. Apraxia is also widely believed to be less severe in Wernicke than in nonfluent forms of aphasia.^{9,10} The present results, however, show apraxia to be more severe in the Wernicke than in the Broca group for all four types of movement (fig). Assessments of relative incidence or severity are of course always subject to sampling bias due to the selection and classification of patients. The results of Poeck *et al* nevertheless merit attention because the carefully balanced design of their experiment minimises many sources of bias that operated in earlier studies.

It is thus the two forms of aphasia with

marked verbal comprehension deficits (Global, Wernicke) that show the most severe ideomotor apraxia here. One might suppose that the test scores for these groups are lowered by their failure to understand some of the commands. Two additional findings reported by Poeck *et al*, however, speak against that explanation. First, the ordering of patient groups by severity is the same for performance to imitation, where verbal comprehension is not involved. Second, the authors present a classification of the errors to axial commands which shows that the type of error is proportionately the same for each group. If comprehension were a significant factor the category that includes failures to understand commands would be disproportionately large in the Global and Wernicke groups.

Failures of comprehension therefore do not appear to explain why the Global and Wernicke groups have the most severe degrees of apraxia. The most likely hypothesis is that the severity of apraxia reflects the average size of lesion in the four groups. In a group study of this kind such an effect could be present even though the correlation between severity of deficit and lesion size may be very small for individual cases. The fact that the pattern of apraxic deficits is the same in the different forms of aphasia, with a strong axial-sparing effect and no significant differences between the three non-axial types of movement, suggests that apraxia cannot be localised to cortical regions associated with specific types of language disorder. Yet it is also true that ideomotor apraxia is practically never seen except in association with some form of aphasia.^{10,11} The lesions for apraxia thus appear to be strongly localised to the language territory of the brain, yet not to any of the subregions of that territory associated with specific aphasic syndromes.

This picture fits nicely with the disconnection model of apraxia proposed by Geschwind. Apraxia for limb and oral commands he attributes to disruption of the pathway from Wernicke's area to the ipsilateral premotor area and thence via the corpus callosum to the contralateral premotor area of the other hemisphere. Any unilateral lesion that interrupts this pathway would almost inevitably produce an aphasia, and the larger the lesion the more likely it is to involve the critical connections. That would explain why the movement disorders of apraxia are strongly associated with the language disorders of aphasia, and also why axial sparing is uniform in all forms of aphasia. Finally, as all non-axial commands must be transmitted over the same pathway, the theory explains why the average severity of

apraxia is the same for movements of the arm, leg, and oral musculature, as the data indicate.

Geschwind's disconnection theory thus accounts for the major features of apraxia brought out by the experiment of Poeck *et al*, as well as for the phenomenon of axial sparing itself. Many details of the theory are still open to question, but its main assumptions receive striking confirmation from these new findings.

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Poeck and Willmes reply

Dr Howes has looked at our data from a perspective that differs from ours in a critical respect. We had chosen to investigate whether performance in the five conditions (oral, arm, leg, bimanual, and axial movements) was different in any one of the four standard aphasia subgroups. This amounts to admitting that the overall null hypothesis: no difference between any of the conditions of apraxia testing for the four patient groups might be tenable. In contrast, Dr Howes has taken Dr Geschwind's view for granted and