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ERROR ANALYSIS AT THE LEVEL OF SINGLE MOVES IN BLOCK DESIGN

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The method of error analysis has been fruitfully applied to the performance of brain-damaged patients in a number of different domains. This approach has also been used for investigating the visuo-constructional abilities of neurological patients, but only in a limited fashion. In the present work we applied error analysis to the performance of three patients, each showing a different pattern of errors, and 12 controls on a modified version of the WAIS Block Design task. Data were collected about the single moves made by the subjects to arrive at a copy of the model, and errors were classified using 14 categories. The error patterns of the three patients were found to be reliably different and so putatively suggest different processing impairments. Patient BV showed errors possibly reflecting the lack, or absence, of a plan during the reproduction attempt. Patient GP mainly showed errors reflecting impairment in the processing of metric spatial relations, while patient VQ’s errors were those predicted by impaired mental rotation ability. Overall, we showed that Block Design performance can be used productively in the investigation of spatial processing by means of the single-case approach.

INTRODUCTION

Detailed analysis of the errors made by patients has been highly productive in a number of different domains and on a number of different levels. Thus the different types of reading errors made by a set of acquired dyslexic patients was the primary empirical motivation for Marshall and Newcombe’s (1973) model, which distinguished between the separable routes by which a word can be read. In another area, the different types of spelling errors made by a single patient, LB, of Caramazza, Miceli, Villa, and Romani (1987), was the primary empirical evidence for the authors’ theoretical claim that their patient could be described as having an impairment to the graphemic output buffer. The existence of perseverations in naming has been seen as the correlate of “priming” in normal subjects (Cohen & Dehaene, 1998) and has been used as evidence for the use of short-term weights to bind different levels of specific processing operations (Plaut & Shallice, 1993). Thus errors may provide information on (1) the separability of processing routes, (2) the function of the critical processing system that is impaired or even (3) an underlying process at the synaptic level.
Error analyses have been carried out much less frequently in the visuospatial domain than in the language domain. In the classical framework of "constructional apraxia" (see, e.g., Kleist, 1934), the performance of brain-damaged patients on complex paper-and-pencil copy tasks have been evaluated, with more attention given to the quantitative aspects of the deficit than to the qualitative error profiles. One major exception is the well-known observation that right-hemisphere patients tend to reproduce single figural details correctly, but fail to reproduce the general organisation of the figure and the spatial relations between the parts. By contrast, left-hemisphere patients are poor at reproducing the details even though they preserve the general outline and spatial relations between the elements (see, e.g., Duensing, 1953). More recently a valuable method of analysis of paper-and-pencil copy performance has been proposed with regard to the Rey-Osterreith Complex Figure (Bennett-Levy, 1984).

Nevertheless, the constructional task that has been most often analysed in terms of error patterns is the Block Design subtest of the WAIS. Many authors have considered it suitable for qualitative analysis (see Kaplan, 1983). Thus Kaplan, Palmer, Weinstein, Baker, and Weintraub (1981; reported by Akshoomoff, Delis, & Kiefner, 1989) found that patients with right-hemisphere lesions break the $2 \times 2$ or $3 \times 3$ square design (broken configurations errors) more often than controls or patients with left-hemisphere lesions. This was confirmed by Akshoomoff et al. (1989). In addition to the right-hemisphere/left-hemisphere difference, Milberg, Hebben, and Kaplan (1996) argued that evidence is available that points to an anterior cortical lesion location in some patients. These come from what are called stimulus-bound errors, where patients focus excessively on what are perceptually the most obvious features of the stimulus.

All of this work has been carried out within the lesion location-based group study methodology rather than the individual case approach. Thus, for studies using this methodology, right-hemisphere patients have been held to distort the overall configuration while left-hemisphere ones are said to have difficulty with internal details (in a similar way as occurs with paper-and-pencil figure copy tasks; Duensing, 1953). The function of the approach is primarily to provide evidence on the localisation of the lesion rather than on the cognitive organisation of spatial processing. Moreover, quantitative analysis of errors is greatly complicated in that the analysis is typically carried out as an adjunct to administration of the WAIS or WISC Block Design, using the standard administration procedures that incorporate a stopping point that will differ according to the subject's performance. Possibly most critically, the error categories are very broad and depend principally on the final configuration achieved, so that error types of potential theoretical interest may not be detected.

In children, Akshoomoff and Stiles (1996) have introduced a more complex categorisation. They have separated out a subclass of broken configuration errors, which they found to occur frequently in 4- to 6-year-old children. This is the rotated matrix, where the whole of a $2 \times 2$ or $3 \times 3$ square arrangement is rotated by 45°. They also added the interesting error type of orientation errors, where the blocks are placed in the proper position within the matrix but one or more of the diagonal block faces are oriented incorrectly. These become the most frequent error type in 7- or 8-year-old children. However, even with this approach, the child’s series of responses to each problem is assigned to only one of four mutually exclusive categories and, again, only the final configuration is assessed.

An analysis limited to the final configuration produced by the subject, as applied by the above investigators, wastes a potential opportunity that the Block Design test provides. As for other types of problem-solving performance (see, e.g., De Groot, 1966), it should also be possible to categorise parts of problem attempts or even individual moves. In this paper we investigate whether this approach can fruitfully be applied to Block Design performance. More detailed analysis of the error patterns in block-moving tasks seems a potentially promising approach and could allow quantitative analysis within the performance of individual patients. However, any procedure for the extraction and classification of errors will have to face three main obstacles:
1. The subject’s performance on any Block Design trial is a complex sequence of actions rather than a single, easily identifiable response.

2. It is not always clear what part of the model the subject is trying to reproduce at any one point of the sequence.

3. Many errors are interpretable in multiple ways, and thus could enter multiple error categories.

In summary, and at variance with previous studies, our aims are:

1. To develop a version of the Block Design without the use of a clinically defined “stopping point”.

2. To propose a method for analysing single moves and not only the final configuration produced.

3. To propose a method for classifying erroneous moves into seven (main) different error categories.

4. To administer the task to individual brain-damaged patients in order to see whether these methods allow one to find specific error profiles.

The empirical section of the paper is organised in the following fashion. First, we introduce the version of the Block Design task that we used. Second, we outline the error classification used. Third, we present, as pilot data, the results from a set of 12 control subjects and of 3 patients with right-hemisphere lesions whom we show to have different patterns of impairment. As a last step, we consider issues of the specificity and reliability of those three error patterns.

METHODS

Experimental procedure

To practice the task subjects were initially administered the first two 2 × 2 models of the original WAIS-R Block Design test (Wechsler, 1981), with the standard instructions and procedures. After completing this part, and whatever the results, subjects were informed they would from then on need to use all nine blocks, and not just four, in order to reproduce each of the models that followed.

Modified Block Design task

Subjects were administered ten 3 × 3 models (Figure 1A), two of which belong to the original set (Wechsler, 1981). The models (5 × 5 cm in size) were presented on the table, just above the workspace of the subject, one at a time in the order specified in Figure 1. The models were printed on 10-cm square cards. Before starting the reproduction of each model, the examiner mixed up the nine blocks in the standard way for Block Design and

Figure 1. (A) Experimental stimuli. (B) Elements of the models are highlighted and numbered.
placed them on the table to the left of the subject. Each subject was asked to pick up one block at a time and add it to his/her product (his/her attempted copy). Subjects were asked to warn the examiner when they thought they had completed the trial.

The time limit was 3 minutes. Subjects were not informed of this time limit, and were allowed to complete the reproduction out of time if, after the 3 minutes, they were very close to the correct solution. Scoring was, however, limited to the performance during the 3 minutes. The examiner sat at the table in front of the subject and recorded his/her performance continuously on a scoring sheet.

Scoring procedure

Before discussing the scoring procedure it is necessary to define some concepts.

1. The model. This is the stimulus pattern to be reproduced.
2. An element. This is a feature of the model that has been considered as “perceptually unitary.” Elements are shown in Figure 1b.
3. The product. This is the set of blocks that are considered to be part of the solution attempt at the particular stage of the attempt being analysed. The following operational criterion is used for when a block is to be treated as part of the product. The subjects put blocks in contact with each other. A contact set is defined as a set of blocks that are in physical contact (horizontally, vertically or diagonally) through a continuous path of whatever length and shape. The first contact set the subject produces (C1) is held to belong to the product by definition. If another contact set C2, detached from C1, is produced, it will not be part of the product, unless (a) a reference frame (RF, see below) is established derived from C1 and (b) C2 has at least one block within the 3 × 3 matrix, of the RF. If a contact set C2, initially detached from the product and outside its 3 × 3 matrix, is then connected to the product by filling the gap with new blocks, all of the blocks of contact set C2 will then be retrospectively assigned to the product.

4. A sequence. This is the set of actions done by a subject in a single solution attempt. A sequence finishes when the time limit is reached, the subject claims s/he finished, or when the subject destroys the product and begins again. Thus, there can be more than one sequence per problem.

A procedure for the extraction and classification of errors in a Block Design task needs to contain: (1) a criterion for breaking down the sequence of actions by the subject into chunks that can be recorded in paper-and-pencil fashion during the experiment; (2) a criterion that permits, in the post-experiment scoring, the mapping of positions in the product to positions in the model (i.e., the reference frame, RF). This is required in order to identify whether a particular block can be considered to be correctly placed; (3) classification rules that disambiguate errors as far as possible, so as to reduce the multiple-category errors to a minimum.

A procedure was developed to address those three points. The entire set of rules is detailed on the website: http://www.sissa.it/cns/papers/blockdesign.pdf. According to this procedure:

1. During the experiment, rules are provided for the examiner to break down the sequence of actions by a subject. Records are made only of moves, i.e., blocks that have been just inserted in the product (insertions) or just erased from the product (deletions) when the subject begins to work on other parts of the product. As a result, the researcher obtains a temporally ordered sequence of moves and products, and is thus able to obtain the overall configuration of the product at any one point of the sequence.

2. For post-experiment scoring, a rule is provided to identify a reference frame—see (2) above—so that a judgement of correctness can be made on each single insertion of a block. To identify a RF, one needs to scan forward the temporal sequence of products; a RF is identified when either a corner of the model is recognisable in the product or a complex element of the model is recognisable. The presence or absence of an identifiable RF in the sequence leads to an initial main distinction. One type of insertion is that of...
sequences where no RF could be identified (RF0 insertions). These correspond to insertions in which the behaviour of the subject does not follow a transparent strategy, and so all of them are defined as errors (RF0 errors). The second type are insertions of sequences within which a RF becomes identifiable (RF1). In this case some insertions are correct (RF1 correct), i.e., those of a correctly oriented block in the correct position according to the RF; all the other insertions are considered as errors (RF1 errors).

3. Errors are classified into different categories. The criteria for an error to enter an error category are made quite restrictive, so as to limit the number of multiple-category errors.

The seven main error types (supra-categories) are given below and more details are presented on the website: http://www.sissa.it/cns/papers/blockdesign.pdf.

RF0 errors

1. Lack of (identifiable) strategy. This category of errors occurs when it is not possible to determine a RF using the criteria given above and, therefore, to identify the strategy being used by the subject. Such errors can be subdivided into the following subcategories:
   (i) the block was not upright;
   (ii) out of spatial limits—when a block is placed three or more blocks from some other block in the product, thus "breaking" the spatial organisation of any possible 3 × 3 matrix of blocks;
   (iii) perseveration—see 3 below;
   (iv) unclassifiable (without RF)—when none of the above categories (i), (ii), (iii) is applicable.

RF1 errors

2. Use of wrong strategy. This refers to situations where it is possible to determine the general strategy used by the subject (because a RF is identifiable), but a fundamental strategic error has been made. The two subtypes are:
   (i) out of the 3 × 3 matrix defined with respect to the current RF;
   (ii) full blocks for diagonals—when a full block face is used instead of a half-red half-white block face ("half block" for short) to reproduce a diagonal feature of the model.

3. Perseveration. When a block is incorrectly put next (vertically or horizontally) to an identical block, in the next move in a sequence.

4. Spatial error. There are two subtypes:
   (i) overestimation—when a dimension of an element of the model is overestimated;
   (ii) position—when a block is misplaced one block away vertically or horizontally.

5. Rotation. When a "half block" or an element composed of at least two blocks is placed at 90° or 180° to its correct orientation. Subcategories are:
   (i) rotation of single block—i.e., of a half block through 90°;
   (ii) red-white confusion—rotation of a half block through 180°;
   (iii) rotation of a complex element.

6. Neglect. When a block is missed out on the contralesional column of the 3 × 3 matrix.

7. Unclassifiable. When a reference frame is identifiable but the error is not of types 2–6.

The complete tree of classification of insertions is presented in Figure 2 overleaf. Insertions are not categorised until a RF is identifiable in the sequence, or until the absence of a RF in the sequence is established. The categorisation of errors can involve working backwards in the sequence. For instance, the error category full blocks for diagonals requires that two full blocks, one red and the other white, have been placed in contact to each other. Thus, only when the analysis reaches the insertion of the second of those two blocks can one label the first block as a full blocks for diagonals error.

1 With the exception of not upright insertions, which are labelled as RF0 insertions even if they are in a sequence with an identifiable RF.
Measures

Error probability estimates

We estimated the probability of a particular error type as the proportion of insertions that fitted that category. This was used instead of the absolute number of errors since the number of insertions varies greatly from subject to subject. The error proportions are useful for comparing the performance of single patients to that of the control sample for diagnostic purposes. There are two error probability estimates, one computed for RF0 errors, the other for RF1 errors.

1. RF0 errors. The presence of RF0 errors appears to reflect the lack of an efficient general strategy for building the product. So, a direct way of estimating the probability of such behaviour will be that of computing the proportion of RF0 errors out of all insertions. This measure was called RF0%.

2. RF1 errors. RF1 insertions can be correct (RF1 correct) or incorrect (RF1 errors). As RF1
errors can only be made in the context of a reference frame (i.e., of a strategy that is very basically appropriate), one needs to estimate their probability in terms of their proportion relative to the overall number (correct plus error) of RF1 insertions. An example will clarify why this is necessary. To diagnose an overestimation error one needs to recognise the element that was overestimated. Elements are recognisable only when a RF is identifiable. Thus, the probability of overestimation errors is estimated in terms of the ratio with respect to the number of RF1 insertions. Similar reasoning can be applied to all other types of RF1 errors. Thus, a subject making 7 overestimation errors out of 50 RF1 insertions, obtains an overestimation proportion of 14%. This measure was called RF1%.

The two measures, RF0% and RF1%, were computed for each atomic and supra-category separately, taking into account also multiple-category errors (see Figure 2 for the complete lists of atomic and supra-categories).

Error profiles that abstract from the general level of performance
We considered the proportion of errors of one type with respect to the overall number of errors (and not of insertions) for the purpose of comparing different error patterns taking into account the effects of differences in the general level of performance. This was done for RF1 errors, and the measure was called RF1%E. Such a parameter allows one to compare the error profiles shown by different patients and by the same patient in different sessions.²

Subjects
Twelve right-handed control subjects (four males, eight females) were recruited whose age (mean = 62.2, SD = 6.9) and education (mean = 7.3, SD = 2.8) were comparable to those of the brain-damaged patients being tested in the region. At the time of testing, they had no history of neurological disease. Three right-handed right-hemisphere patients, who had been admitted to the Ospedale Gervasutta (Udine), were studied. They showed neither visual neglect, as assessed by means of the Letter Cancellation and the Star Cancellation tests of the BIT (Wilson, Cockburn, & Halligan, 1987), nor more than mild early visual processing disorders, as assessed by means of the VOSP battery (Warrington & James, 1991). The clinical and demographic details of the patients are reported in Table 1.

RESULTS
Table 2 reports the range of performance produced by the normal subjects and the results of the three patients categorised according to the complete error classification tree (all atomic categories). Figure 3 shows the same results in terms of a simplified classification that merged some groups of atomic categories into the supra-categories, as discussed in the Scoring Procedure section. In Figure 3, the first column on the left shows RF0% values and all the other columns show RF1% values. Multiple-category errors were included as well as unambiguous errors in this quantification.

The distribution of values of the control sample (n = 12) was often skewed. Indeed in all cases, with one minor exception, the maximum value obtained by one of the 12 controls was greater than mean +1.645 SD (i.e., the one-tailed 5% cut-off according to the normal distribution). Therefore it was considered appropriate to treat the maximum value of the control sample as a normality cut-off. The resulting normal ranges are reported as vertical

² If 80% of the errors of a subject are of category X (RF1%E = 80), this does not necessarily mean that the subject has a pathological frequency of X errors. He may well have made, for instance, only 5 errors (4 X, 1 non-X) out of 100 insertions, i.e., a very low frequency. For this reason, RF1%E cannot be used for the diagnosis of a deficit on a single error category (RF1% has to be used for that purpose). Note also that RF1%E can only be used to compare the error profiles of subjects who make a high number of errors (as some patients do); subjects who make too few errors have very unstable RF1%E scores (e.g., a subject making a single RF1 error will have a RF1%E score of 0% for all categories but one, which will have a score of 100%).
bars in Figure 3. The scores of the three patients are reported as lines.

Table 3 presents the same analysis as illustrated in Figure 3 more fully. It also reports the overall level of performance for each patient, quantified as the average number (across the 10 problems) of correct blocks achieved (maximum: 9). For each problem, the maximum number of correct blocks achieved at any point of the sequence was considered. Inspection of Figure 3 and Table 3 shows that the three patients were characterised by rates well outside the normal ranges for some error types. Patient GP did so on the lack of strategy and spatial error categories. By contrast, patient BV exceeded the normative range on lack of strategy, use of wrong strategy, and perseveration with RF. Patient VQ

Table 2. Results of the classification in terms of atomic errors categories. RF0% values are reported for the first four error categories (columns), RF1% in the remaining columns

<table>
<thead>
<tr>
<th></th>
<th>RF0&lt;sup&gt;ab&lt;/sup&gt;</th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>1(iv) 1(i) 1(ii) 1(iii)</td>
<td>2(i) 2(ii) 3 4(i) 4(ii) 5(i) (5ii) 5(iii) 6 7</td>
<td></td>
</tr>
<tr>
<td>Normal controls</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Mean</td>
<td>0.5 0.3 0 0</td>
<td>1.2 3.5 2.3 3.3 5.1 5.4 2.2 2.1 0 1.3</td>
<td></td>
</tr>
<tr>
<td>SD</td>
<td>1.8 0.9 0 0</td>
<td>2 3.4 2.1 3.7 4 5.6 2.7 3.1 0 2.4</td>
<td></td>
</tr>
<tr>
<td>Mean + 1.645 × SD</td>
<td>3.5 1.7 0 0</td>
<td>4.5 9.1 5.8 9.3 11.7 14.6 6.8 7.2 0 6.3</td>
<td></td>
</tr>
<tr>
<td>Maximum</td>
<td>6.2 3.1 0 0</td>
<td>5.7 11 7.1 13.3 13.3 16.7 8.6 9.8 0 7.3</td>
<td></td>
</tr>
<tr>
<td>Patients</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GP</td>
<td>1.1 2.2 6.5 7.6</td>
<td>3.6 3.6 7.2 22.9 7.2 3.6 0 2.4 1.2 0</td>
<td></td>
</tr>
<tr>
<td>BV</td>
<td>2.6 22.5 7.3 13.9</td>
<td>14.3 17.9 17 13.4 8.9 7.1 1.8 2.7 0 0</td>
<td></td>
</tr>
<tr>
<td>VQ</td>
<td>10.9 7.6 5 2.5</td>
<td>5.4 4.3 7.6 3.3 6.5 22.8 1.1 9.8 0 5.4</td>
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<tr>
<td>Replications</td>
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<td>3 5 5 6.1 5 3 6.1 3 0 8.1</td>
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<tr>
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<td>1.3 5.1 7.6 7.6 10.1 1.3 7.6 0 0 3.8</td>
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<tr>
<td>BV2</td>
<td>4.8 18.4 7.5 13.6</td>
<td>12.7 6.4 13.6 9.1 7.3 5.4 2.7 2.7 0 4.5</td>
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<tr>
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<td>13.6 6.4 12 9.6 13.6 9.6 2.4 6.4 0 4</td>
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<tr>
<td>VQ2</td>
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<td>2.6 1.8 3.5 4.4 18.6 21.2 8 4.4 0 3.5</td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> Mean, SD, Mean + 1.645 × SD and maximum values for normal controls are reported. Values in italic indicate performance above the maximum values recorded in the control sample.

<sup>b</sup> RF0: 1(iv) unclassifiable (without RF); 1(i) not upright; 1(ii) out of spatial limits; 1(iii) perseveration (without RF).

<sup>c</sup> RF1: 2(i) out of matrix; 2(ii) full blocks for diagonals; 3 perseveration (with RF); 4(i) overestimation; 4(ii) position; 5(i) rotation of single blocks; 5(ii) red/white confusion; 5(iii) rotation of a complex element; 6 neglect; 7 unclassifiable (with RF).
instead showed deficits on the lack of strategy and rotation error categories. The three patterns share a common characteristic, i.e., the presence of a high rate of lack of strategy (RF0) errors, just outside the normal range for GP and clearly abnormal in BV and VQ. On the other hand, the three profiles differ markedly in the distribution of RF1 errors.

To substantiate these differences in statistical terms, we compared the three RF1 profiles only considering “unambiguous” errors (i.e., errors that entered a single category). The Exact test could be applied on the frequencies of these mutually exclusive errors, which are reported in Table 4. All the three pairwise comparisons showed significant differences between the profiles (GP vs. BV, \( p = .004 \); GP vs. VQ, \( p < .001 \); BV vs. VQ, \( p = .003 \)). The source of such differences is clear: 69% of GP’s “unambiguous” errors were spatial errors, as impaired to 21% for BV and 6% for VQ. Fifty per cent of BV’s “unambiguous” errors were use of wrong strategy errors as compared to 12% for GP and 19% for VQ. Fifty per cent of VQ’s were rotation errors compared to 12% for GP and 21% for BV.

Robustness of the findings

How robust are these findings across patients? This was investigated in a subsidiary study with BV, GP, and VQ.

Method

The three patients underwent further testing sessions using the same task. BV and GP performed session 2 and session 3, and VQ just session 2. Session 2 was composed of the same stimuli as those in Figure 1a, except that they were red-white reversed and presented in the opposite order. Session 3 was identical to the first session. BV and GP performed the three sessions one week apart.
Session 2 was performed 7 months after the first session by VQ.

Results
All three patients improved with each testing but not dramatically (cf. the overall level of performance in Table 3: GP, GP2, GP3; BV, BV2, BV3; VQ, VQ2). Figure 4 shows the profiles of the repeated sessions for each patient. The performance of each patient is expressed in terms of RF1% scores, i.e., measures that allow one to compare the error patterns, partialling out the effects of between-sessions variations in the absolute error frequencies. The patterns clearly replicate for patients BV and VQ. Although patient GP's most frequent error category is always overestimation.

Table 3. Results of the classification in terms of supra-categories. RF0% values are reported for the lack of strategy error category, RF1% for the remaining error categories. The last three columns report (Perf.) the overall level of performance for each patient (see text for details); (No. moves) the overall number of moves (i.e., the denominator of the RF0% scores); (RF1 moves) the overall number of RF1 moves (i.e., the denominator of the RF1% scores).

<table>
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<th>Control subjects</th>
<th>RF0b</th>
<th>RF1c</th>
<th>Perfd</th>
<th>No. movese</th>
<th>RF1 movesf</th>
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<td>7.4</td>
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<tr>
<td>Mean + 1.645 × SD</td>
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<td>16.6</td>
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<tr>
<td>Maximum</td>
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<td>16.2</td>
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<td>Patients</td>
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<td>GP3</td>
<td>25.8</td>
<td>30.4</td>
<td>17.0</td>
<td>18.8</td>
<td>8.9</td>
</tr>
<tr>
<td>BV2</td>
<td>22.7</td>
<td>9.8</td>
<td>7.6</td>
<td>9.8</td>
<td>25.0</td>
</tr>
<tr>
<td>BV3</td>
<td>9.2</td>
<td>8.1</td>
<td>5</td>
<td>11.1</td>
<td>10.1</td>
</tr>
<tr>
<td>VQ2</td>
<td>5.9</td>
<td>6.3</td>
<td>7.6</td>
<td>15.2</td>
<td>8.9</td>
</tr>
<tr>
<td></td>
<td>25.2</td>
<td>19.1</td>
<td>13.6</td>
<td>14.5</td>
<td>9.1</td>
</tr>
<tr>
<td></td>
<td>14.4</td>
<td>18.4</td>
<td>12.0</td>
<td>19.2</td>
<td>16.8</td>
</tr>
<tr>
<td></td>
<td>20.2</td>
<td>3.5</td>
<td>20.4</td>
<td>29.2</td>
<td>2.0</td>
</tr>
</tbody>
</table>

Table 4. Absolute and relative frequencies of unambiguous RF1 errors for the three critical patients on session 1.

<table>
<thead>
<tr>
<th>Use of wrong strategy</th>
<th>Perseveration</th>
<th>Spatial</th>
<th>Rotation</th>
<th>Neglect</th>
<th>Unclassifiable</th>
</tr>
</thead>
<tbody>
<tr>
<td>GP</td>
<td>2 (12.5%)</td>
<td>0 (0%)</td>
<td>11 (68.8%)</td>
<td>2 (12.5%)</td>
<td>1 (6.3%)</td>
</tr>
<tr>
<td>BV</td>
<td>14 (50%)</td>
<td>2 (7.1%)</td>
<td>6 (21.4%)</td>
<td>6 (21.4%)</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>VQ</td>
<td>6 (18.8%)</td>
<td>3 (9.4%)</td>
<td>2 (6.3%)</td>
<td>16 (50%)</td>
<td>0 (0%)</td>
</tr>
</tbody>
</table>
errors, his pattern of performance is more variable
across sessions (see Figure 4A). Nevertheless, the
differences between GP’s pattern and those of BV
and VQ are stable, and invariant across testing
sessions, for the other two crucial error categories
(*use of wrong strategy* and *rotation* errors). This was
investigated by means of two logistic regression
analyses. In a first analysis, we studied the relative
frequency of *use of wrong strategy* errors (RF1%E, as
shown in Figures 4A and 4B) as a function of
patient (GP vs. BV) and session (1/2/3). In a
second analysis, the relative frequency of *rotation*
errors (RF1%E, as shown in Figures 4A and 4C) was
studied as a function of patient (GP vs. VQ) and session (1/2). As can be seen in Table 5, patient
GP made less *use of wrong strategy* errors than BV,
and less *rotation* errors than VQ, irrespective of the
session. Thus the differences between the three
profiles shown in Figure 4 are basically reliable.

**Discussion**

What distinguishes the three patterns as far as the
RF1 errors are concerned? The rate of production
of both *use of wrong strategy* errors and *perseveration* (*with RF*) errors is much higher for BV on all three
trials than for any normal control or any trial of GP
or VQ (see Table 3). VQ shows the same type of
characteristic for *rotation* errors. GP consistently
produces more spatial errors than any other supra-
category (see Table 3, Figure 4A) but the value is
not consistently more than maximum normal
control or the numbers produced by the other two
patients (see Table 3). Where GP differs from the
two other patients is in the relative lack of the RF1
errors they produce most frequently (BV: *use of

![Graphs](https://via.placeholder.com/150)

Figure 4. Qualitative error profiles for patients GP (A), BV
(B), and VQ (C) across testing sessions. Abbreviations as in Figure
3.

wrong strategy* and VQ: *rotation* errors). Since GP is
also consistently outside the normal range on
overall level of performance (see Table 3), we will
provisionally consider this as a third error pattern.

| Table 5. Results of the logistic regression analysis on RF1%E proportions |
|------------------|------------------|--------|--------|
| **Error**        | **Source**        | **Wald** | **df** | **p**  |
| Use of wrong strategy | Patient (GP vs. BV) | 15.64   | 1      | .0001  |
|                  | Session (1/2/3)   | 0.70    | 2      | .7051  |
|                  | Patient × Session | 2.44    | 2      | .2956  |
| Rotation         | Patient (GP vs. VQ) | 16.27   | 1      | .0001  |
|                  | Session (1/2)     | 3.24    | 1      | .0717  |
|                  | Patient × Session | 0.57    | 1      | .4516  |
GENERAL DISCUSSION

A much more detailed method for analysing the errors of neurological patients on tasks modelled on WAIS Block Design has been developed. It operates by analysing in detail the sequence of moves a patient makes rather than by attempting to categorise the final construction, as is typical of the clinical and developmental literature. On the current approach the subject’s incorrect performance on each attempted insertion of a block was placed in 14 categories, which it should be noted are not entirely mutually exclusive. Moreover, instead of the standard clinical procedure such as that used in WAIS Block Design with a variable stopping point, a fixed set of problems was used as, for instance, was also the case in Akshoomoff and Stiles (1996).

We have described three right-hemisphere patients who showed different patterns of performance, each of which also differed from those of normal subjects and was replicable across different sessions. The method is thus promising as a reliable tool for providing an initial functional difference between patients with constructional difficulties in the visuospatial domain. As has already occurred in different neuropsychological domains, this error-based broad classification of patients can lead to theoretically relevant single-case studies that allow inferences on the fractionation of the cognitive system (see, e.g., Caramazza et al., 1987; Cohen & Dehaene, 1998; Marshall & Newcombe, 1973) and, as an advantage with respect to the time-honoured double-dissociation method, even on the local features of a single processing module (see, e.g., Plaut & Shallice, 1993).

A detailed single-case analysis of each of the three main impairment profiles involving additional tasks would be beyond the scope of the present work. Nevertheless, as an initial step towards further investigation, we will suggest some possibilities as to the specific functional deficits. The third patient, in particular, illustrates most clearly what we view as the advantages of the error analysis method.

All of the three patterns of performance included a value outside the normal range on lack of strategy (RF0) errors. Pattern I, exhibited by patient BV, is the closest to that held to be typical of patterns produced by right-hemisphere patients, namely as the distorting of overall configurations (see Kramer, Kaplan, Share, & Huckeba, 1999, for discussion). Thus the pattern includes more not upright, out of spatial limits, and out of matrix errors than shown by normal subjects (see the top row of Figure 5 for examples of errors of the first two categories by BV). By contrast, the pattern does not include model-internal errors such as overestimation, position, and rotation errors, as these are within the normal range for BV. This profile would be predicted by assuming damage to the planning and monitoring stages of the supervisory system operations (Shallice & Burgess, 1996). The planning and monitoring failures would consist of lack of use of two implicit rules that normal
subjects acquire very early in the test and which are used by them to catch possible errors. These rules are (1) that blocks always need to be upright and (2) that each array has a $3 \times 3$ structure. BV's not upright errors are a direct expression of failure to use rule (1). They cannot be interpreted in terms of lower level impairments, as for instance an inability to reproduce the orientation of a single block independent of its context (as can occur in certain right parietal patients, see e.g., in Warrington, 1969), since all except one of those errors occur when BV attempts to reproduce a diagonal stripe (see, the top row of Figure 5). On the other hand, BV's out of spatial limits and out of matrix errors are direct expressions of failure to use rule (2). Most of these errors occur when BV inserts an additional block when faithfully reproducing a required pattern at an inappropriately enlarged size due to not dealing suitably with diagonals (see also full blocks for diagonals errors in Table 2). (The out of spatial limits and not upright errors also correspond to what Milberg et al., 1996, called stimulus-bound errors.)

Pattern II is that exhibited by patient GP. This was characterised by an increase in overestimation errors as well as the lack of strategy (RF0) errors, but without an increase in rotation errors. By contrast patient VQ, who exhibits pattern III, shows a double dissociation in this respect with patient GP. In pattern III an increase in the rotation errors coexists with a normal rate of overestimation errors, although again there is an increase in the lack of strategy errors.

Figure 5 (middle and bottom rows) illustrates examples of errors by GP and VQ.

One possible explanation for pattern II is that it occurred as a result of a double deficit. One deficit would be a failure of certain of the metric type of spatial operations often assumed to involve right-hemisphere processing, where there are inadequacies in estimating quantitative variables pertaining to spatial stimuli such as in lengths, angles, and so on (Kosslyn, Koenig, Barrett, Backer, Cave, Tang, & Gabrieli, 1989). In the present case the variable would be length. Since overestimation errors can be caught by simple counting operations, it seems likely that this metric operation failure coexists with a second impairment. This would again be of a checking operation often postulated to account for activation in right dorsolateral prefrontal cortex (see Fletcher, Shallice, Frith, Frackowiak, & Dolan, 1998; Henson, Rugg, Shallice, & Dolan, 2000; Henson, Shallice, & Dolan, 1999; Shallice, 2002; Shallice, Fletcher, Frith, Grasby, Frackowiak, & Dolan, 1994), a process closely related conceptually to that held to be carried out by Posner and Petersen’s (1990) vigilance system in attention tasks. In other words the patient might have failed to check that a response that was visually fairly appropriate was indeed completely correct.

Error pattern III possibly constitutes the quantitative specification of a performance that one of us with colleagues has recently described in another patient, PAO (Bricolo, Shallice, Priftis, & Meneghello, 2000). This patient suffered from a right-hemisphere lesion and presented with a difficulty in tests such as Kohs’ Blocks (Roser, 1991), a more complex test analogous to Block Design. The difficulty manifested itself in an inability to rotate to its correct position a two-colour block face where the colours are divided by a diagonal, as in Block Design. When the patient had selected the correct block but had placed it in the wrong orientation, he would search for another block of the same type in the hope that the relevant face correctly matched the target rather than by physically rotating the original block to the correct position. This can be interpreted as an inability to mentally rotate external objects (see, e.g., Harris, Egan, Šonkilla, Thocon-Dangui, Paxinos, & Watson, 2000; Tomasino, Toraldo, & Rumiati, 2003). In light of further experimental investigation, Bricolo et al. (2000) concluded that PAO’s mental rotation deficit was caused by a specific inability to maintain invariant the “categorical” positions of details inside a figure after this has been mentally rotated. Thus, for instance, when PAO was shown a tilted square frame containing a dot at its top-left corner, and asked to reproduce the dot position inside an upright frame, he set the dot in its top-right corner. These “categorical” errors (i.e., left/right or top/down reversals, see Kosslyn et al., 1989) appeared in spite of PAO’s spared ability to process the metric
position of the dot inside the frame. In fact, when the dot had been placed in the correct categorical position (i.e., in the correct quadrant), it was also in the correct metric position.

Patient VQ exhibited a pattern of errors on Block Design analogous to those exhibited by PAO on Kohs’ Blocks. VQ was therefore tested on the experimental task of frame rotation used with PAO, together with an extended set of tests of the same type. She was impaired on these tasks and made qualitatively similar “categorical” errors. She thus presented with an analogous processing impairment to PAO. This supports the idea that error pattern III can be attributed to an impairment in forming categorical spatial representations or in operating on them (see Toraldo & Shallice, 2004), thus confirming the basic premise of the paper that distinguishing different internally reliable error patterns in spatial operations can be productive for isolating the processes that underlie them in the individual patient.

CONCLUSIONS

We have shown that at least three distinct patterns of errors are produced by individual patients with right-hemisphere lesions in tasks related to Block Design. Moreover, we have found that the difference in patterns is reliable over testing sessions. In one case we have demonstrated that the characterisation of a specific error pattern can provide the initial step in selecting a patient for a more detailed study of the underlying processes that are impaired, in the same way as initial characterisation of error patterns was productive in the acquired dyslexias (e.g., Marshall & Newcombe, 1973) and the acquired dysgraphias (e.g., Caramazza & Miceli, 1990; Caramazza et al., 1987). Overall the study shows that the Block Design type of task is potentially productive for a single-case approach to the investigation of spatial operations.

REFERENCES


