Impairments of trunk movements following left or right hemisphere lesions: dissociation between apraxic errors and postural instability

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Summary
Stroke patients present with apraxic or postural deficits involving trunk movements. Praxis and posture control have been associated with the functions of the left and the right hemisphere, respectively. For the first time, in this study the occurrence of apraxic and postural components in trunk movement deficits following right and left hemisphere lesions were investigated in the same participants. Twenty-three patients with left (L/pt), 12 with right (R/pt) hemisphere lesion, and 30 healthy controls were evaluated with a 21-item test assessing the imitation of meaningless, symbolic and reaching movements presented twice on visual or proprioceptive modality. Erroneous, motor responses of the trunk were classified as postural (compensations to overcome stability or asymmetry deficits) or apraxic (execution errors not due to biomechanical constraints). Postural instability reactions were significantly more frequent among the R/pts, whilst apraxic responses were overwhelming within the L/pts. The findings are consistent with the view that the left hemisphere is dominant for praxis and suggest that this dominance be extended to trunk praxis. The results also support the hypothesis that trunk postures are coded in relation to the environment by a representational system. A widespread network, mainly sitting in the right hemisphere, subserves this postural system. The distinction between praxic and postural deficits in executing trunk movements should be kept in mind when evaluating trunk movement difficulties shown by stroke patients, in following up their recovery or when tailoring rehabilitation programmes.

Keywords: stroke; apraxia; posture; trunk

Abbreviations: L/pt = left hemisphere lesion patient; R/pt = right hemisphere lesion patient

Introduction
Stroke patients may show deficits of strength or tone in trunk muscles (Gillen, 1998; Tanaka et al., 1998; Dickstein et al., 2000). Apraxia (Rataj and Korohoda, 1969; De Renzi and Faglioni, 1999) or postural unbalance (Cirstea and Levin, 2000) could also impair trunk movements. Praxis and posture control have been associated with the functions of the left (Faglioni and Basso, 1985) and the right hemisphere (Pérennou et al., 1996), respectively. The aim of this study was to investigate the occurrence of apraxic and postural components in trunk movement deficits following right and left hemisphere lesions.

Trunk apraxia and the left hemisphere
Trunk movement impairments, labelled ‘trunk apraxia’, have been reported within a syndrome associated with (bilateral) frontal lobe lesions which encompassed stance and gait apraxia (e.g. Rumpf; Stand and Gangapraxie – Kleist, 1907; Mayer and Barron, 1960; see case descrip-
tions and reviews by Petrovici, 1968; Della Sala et al., 2002). However, patients whose trunk apraxia was overwhelming have been described (e.g. van Vleuten, 1907). In a different context, trunk impairments have been studied as part of disorders of ‘axial’ movements (Poëck, 1985), comprising movements of the eyes and mouth, conceived as a typical apraxia, and investigated together with limb apraxia, to support or to reject their association (Liebermann, 1900).

Geschwind (1975) denied a relationship between axial apraxia and lesion in the left hemisphere. He maintained that left-hemisphere damaged patients affected by both aphasia and ideomotor apraxia could nonetheless perform axial movements on command. He reported anecdotally on patients showing severe face and limb apraxia who performed axial movements on command with no hesitation, for instance when asked to ‘bow, kneel, march or stand to attention’. Poëck and colleagues challenged the hypothesis that the left hemisphere had little involvement in axial movement planning, and maintained that ‘many of the left-hemisphere patients performed considerably below the maximum score obtainable’ (Poëck et al., 1982). Indeed, they reported no difference between oral, arm, leg, bi-manual and axial movements in left hemisphere-damaged patients showing different kinds of aphasias (for diverging points of view, see Howes, 1988; Poëck and Willmes, 1988).

Also the aphasic patients tested by Alexander and colleagues and Hanlon and colleagues performed rather poorly in tests assessing trunk apraxia even if their score in axial movements items was higher than those taxing movements with other body parts, both on command and on imitation modality (Alexander et al., 1992; Hanlon et al., 1998).

Taken together these results seem to suggest that the left hemisphere plays a critical role in axial movement planning. Interestingly, the study by Poëck and colleagues also included a group of patients with right hemisphere lesions who performed flawlessly in their test assessing axial movements (Poëck et al., 1982). None of the other studies included patients with right hemisphere lesions, hence they did not address directly the issue of the relationship between trunk apraxia and the site of lesion.

Moreover, the studies available in the literature are difficult to compare with one another. Geschwind (1975) used only verbal commands, hence excluding severe aphasics from his observations. He asked participants to reproduce whole body positions that also involved the limbs (e.g. the boxer’s position), making it hard to detect apraxic errors, unless very gross, due to the great number of possible options available to solve the task, and making it difficult to disentangle specific trunk disorders from limb apraxia. Poëck and colleagues and Hanlon and colleagues used non-representational gestures on imitation modality, but these were mainly eye movements, 8 out of 13 and 7 out of 10 in the two studies, respectively. The association between left-hemisphere lesions and trunk apraxia is therefore still open to debate (De Renzi and Faglioni, 1999).

**Postural control deficits and the right hemisphere**

The second component involved in the *Rumpf, Stand and Gangapraxie* syndrome (Kleist, 1907) is stance, i.e. the reference posture. Posture ensures balance against gravity and serves as a reference frame for organizing movements (Massion, 1998). Trunk muscles are crucial to postural stability. Postural deficits are frequently observed in clinical practice after brain lesions (Tyson, 1999; Pinedo Otaola and de la Villa, 2000) and are considered as a key issue in rehabilitation programmes (Albert, 1969; Bobath, 1978; Davies, 2000).

Early clinical observations hinted at the association between right-hemisphere lesions and postural deficits (Held et al., 1975; Wade et al., 1984), later confirmed by experimental studies (Bohannon et al., 1986; Hesse et al., 1994; Ustinova et al., 2001). For instance, Rode and colleagues, using a statokinesimetric platform, demonstrated that patients with lesions in the right hemisphere showed a larger sway area and more lateral displacement than patients with left lesions (Rode et al., 1997). They concluded that right-hemisphere-damaged patients may suffer from a persistent distortion of ‘spatial postural representation’. By means of a clinical evaluation with a large sample of stroke patients, Pèrennou and colleagues postulated the existence of a right hemispheric dominance for postural control (Pèrennou et al., 1999). The interaction between postural deficits of the trunk and right-hemisphere lesions calls for refinements.

**Aims of the study**

The interplaying of the systems for praxis and posture control allows humans to perform actions and manipulate the environment (Kuypers, 1981). It is possible that the two hemispheres play a different role in the control of trunk apraxia and posture. No previous study had investigated the occurrence of apraxic or postural deficits in the execution of the same trunk movements in left- and right-brain-damaged patients. This was the main aim of the current study. To this end, we carried out a qualitative analysis of individual motor responses in a series of patients affected by the sequelae of unilateral cerebro-vascular lesions disentangling praxic from postural instability reactions. Differently from previous research on trunk movements in stroke patients, we used a large set of items, tested the participants while sitting, included solely axial gestures centred on the trunk, considered only trunk movements errors (also when the target gesture involved the participation of limbs), and used both visual and proprioceptive modality of presentation of the gesture to be imitated. Patients with a left- or a right-hemisphere lesion, as well as controls, entered the study
aimed at verifying the supposed asymmetrical dominance for praxis and postural trunk control.

Methods

Participants

Participants were recruited within a consecutive series of stroke patients attending a physiotherapy ward. To be considered for the experiment, patients had to fulfill the following criteria: (i) be right-handed; (ii) be younger than 80 years of age; (iii) have had a CT (or MRI) verified single vascular lesion confined to the territory of the middle cerebral artery of one hemisphere no earlier than 2 weeks before the experimental testing session; (iv) prove able to sit upright without external support for at least 45 min; (v) show no overt signs of cognitive deterioration.

Twenty-three patients with left- (L/pts) and 12 with right- (R/pts) hemisphere lesion fulfilled the inclusion criteria and were considered for the study. Six L/pts and five R/pts had a hemorrhagic stroke. All the remaining patients had had an ischaemic stroke. The lesion of eight (35%) L/pts and five (42%) R/pts encroached upon the frontal lobe; the stroke of seven L/pts and five R/pts damaged subcortical areas only.

The L/pts were 10 men and 13 women with 5.7 (SD 2.3, range 3–13) mean years of formal education, their mean age at the time of testing was 65.4 (SD 10.7, range 36–79). They were tested on average 113.3 days (SD 92.4, range 18–330) after their stroke. The R/pts were six men and six women with 7.8 (SD 5.4, range 2–18) mean years of formal education, their mean age at the time of testing was 54.1 (SD 12.1, range 33–71). They were tested on average 107.8 days (SD 54.0, range 19–194) after their stroke. The two groups differed only in age \( t(33) = 2.85, P < 0.01 \). The individual severity of the patients’ motor and sensory deficits was assessed by means of a standardized neurological examination that consists of measuring the strength and tactile sensorial integrity of the upper and lower limbs (Bisiach et al., 1986). Motor impairment of the upper limb was assessed by asking the supine patient to hold their arm flexed with forearm extended and supinated and fingers abducted for 30 s. Motor deficit of the lower limb was assessed by asking the supine patient to hold their thigh flexed at 90° and leg flexed at 90° for 30 s. Scores are given on a four-point scale: 0 = no deficit; 1 = lowering of the limb without reaching the bed surface within 15 s; 2 = limb reaches the bed surface within 15 s; 3 = limb reaches the bed surface within 5 s; for each limb. Somatosensory impairment was assessed by giving 10 single and 10 double symmetrical and simultaneous tactile stimuli on the dorsal surface of either the hand or the foot. Scores are given on a four-point scale: 0 = no deficit; 1 = less than eight double, but more than seven single stimuli are perceived; 2 = four to seven single stimuli are perceived; 3 = less than four single stimuli perceived, for each limb. Therefore, the overall score of this examination ranges from 0 (normal) to a maximum of 6 for both the motor and the sensory sections (Bisiach et al., 1986). The L/pts and the R/pts did not differ in motor \( t(33) = 0.187, \text{n.s.} \) or sensory severity \( t(28) = 0.817, \text{n.s.} \) scoring, respectively, 3.3 (SD 5.1) and 3.2 (SD 2.5) in the motor, and 0.9 (SD 3.9) and 1.5 (SD 4.2) in the sensory examination. [Five L/pts could not be tested with the sensory examination due to their sever aphasia.] Fifteen L/pts scored below the cut-off in the Token Test (De Renzi and Faglioni, 1978), a test assessing language comprehension often used to ascertain the overall severity of aphasia (Boller, 1968; De Renzi and Vignolo, 1979). Eight of them also failed a clinical gestural imitation test assessing ideomotor apraxia (De Renzi et al., 1980), as did two further L/pts who had no language problems. Three R/pts showed signs of neglect on tests of crossing out visual targets (Albert, 1973; Gauthier et al., 1989).

Thirty healthy people, 15 men and 15 women whose mean education was 8.2 years (SD 3.6, range 5–18) and mean age was 60.9 years (SD 9.4, range 45–79), entered the experiment as the control group.

All participants gave informed consent according to the declaration of Helsinki (World Medical Association, 2000).

Testing procedures

Trunk movements were formally evaluated with a 21-item test devised for the purpose of the study (see Appendix I). The battery comprised 12 meaningless, four reaching and five symbolic movements. The four reaching movements required the use of the unimpaired, ipsilesional arm and hand; however, only the trunk movements were considered in the score. As has been repeatedly noted (e.g. Bernstein, 1967; Hanlon et al., 1998), trunk movements have fewer degrees of freedom than limb movements; hence trunk ‘errors’ would have fewer chances to emerge. To analyse trunk movements in some detail, it was decided not to limit the scoring to accuracy, but to further consider the quality of each wrong response and classify the performance of single motor segments.

Participants underwent the whole battery twice on two modalities of imitation: visual and proprioceptive. On the visual condition, participants were told to imitate the same movement performed by the examiner sitting in front of them, as if in front of a mirror. On the proprioceptive condition, the examiner would perform the gesture moving the body of the participant who would feel it passively and attempt to repeat it immediately afterwards. The order of presentation of the two conditions was counterbalanced across participants. When participants successfully reproduced the target gesture, they were presented with the next item. When they failed, the same item was presented again, for a total of three times, before introducing the next item. Hence each item could be performed correctly (on either the first, the second or the third attempt), or, when consistently failed, be considered for error analysis. This procedure gave rise to two scores: the total number of correct responses, ranging from 0 to 21 in each modality; and the total number of repetitions (second and
third trials for each item), ranging from 0 (flawless performance) to 42.

The qualitative analysis was carried out considering two categories of errors: postural and apraxic. Postural instability reactions are broadly defined as compensatory strategies put in place to overcome difficulties in maintaining stability and axial symmetry while performing the requested trunk movement (Massion, 1994; Pérennou et al., 1999). In agreement with published scales assessing motor deficits (e.g. Poole and Whitney, 1988) postural instability reactions not only encompass faulty trunk movements as such, but also the use of the non-paretic arm and leg as support to prevent falls. Asymmetrical executions and non-synergic contractions were visually detected in all items requiring concordant movements. For example, when required to shrug their shoulders, the patient may fail to raise the trapezius muscles in unison.

On the other hand, following Poeck and colleagues, an execution was classified as apraxic if the participant produced with normal strength, erroneous movements that lacked compensatory goal (Poeck et al., 1982). Performances whose flaw could hardly be classified as either postural or apraxic, e.g. when the movement was incomplete or not performed at all, were grouped separately as ‘ambiguous or other’ errors. The category ‘other’ errors also included responses that were neither apraxic nor paretic such as right/left confusion, i.e. the patient making a mirror trunk movement rather than that requested, or attempting to use the paretic rather than the healthy hand in reaching tasks. Postural, praxic, and other error types considered in the study are listed in Table 1.

Wrong responses could be characterized by multifarious errors which were registered individually. When all errors featuring in a single response were postural or apraxic, the response was classed as such. When both compensatory attempts and apraxic features were detected in the same response, this was classed as mixed. A response featuring ambiguous elements was always classed as ‘other’. Therefore, each failed attempt to the third trial for each item was scored as postural, apraxic, mixed or other.

Participants gave formal consent to be tested and were assessed individually. They were sitting on two weighing scales on a low bench facing the examiner. The two scales were identical (45 cm × 27 cm) and of type used to weigh one-self by standing up. These two scales were used to assess asymmetries in weight bearing by measuring weight transfer in each experimental condition, yielding objective detection of any asymmetry and permitting reproducibility of the study. At the start of the examining session the patients were asked to sit upright (on the scales) with their hands on their knees and their feet well balanced on the floor. Baseline weight-bearing asymmetry towards the paretic side was observed in six (50%) R/pts and in eight (35%) L/pts. Baseline asymmetry towards the non-paretic side was observed in two (17%) and four (17%) R/pts and L/pts, respectively. The examiner then corrected any starting asymmetries to ensure that both hip joints were fixed firmly on the scales with the patient’s hips and knees flexed at 90°. Finally, the examiner carefully explained to the participant the instructions both verbally and miming. A series of run-in trials was carried out to ensure that participants grasped their task. The examiner intervened during the test to correct any asymmetry in the starting position before the new item was given. A response was considered asymmetrical when a weight-bearing difference ≥10% of the patient’s body weight was detected on the two scales. Three L/pts and one R/pt were tested a second time on the following day for the sake of test-retest reliability.

All testing sessions were video-recorded and scored subsequently. The few doubts about the presence of a given error or its classification have been openly discussed to reach a unanimous conclusion.

Results

The mean accuracy score and total number of additional presentations required by controls, L/pts and R/pts, in the visual and proprioceptive imitation tasks, are reported in Table 2. The controls’ performance was close to ceiling for both experimental conditions and they required very few repetitions.

Both groups of patients performed clearly worse than the controls: the best performing patient scored less than the worst control. The percentage of correct answers and total number of repetitions were entered in two 2 (groups) × 2 (condition) analysis of variance. The accuracy of L/pts and R/pts did not differ \( F(33) < 1 \). The difference in performance between the proprioceptive and the visual task fell just short of significance \( F(33) = 3.548, P = 0.068 \), but no interaction group × task emerged \( F(33) < 1 \). The two groups of patients did not differ in the total number of repetitions \( F(33) < 1 \). Repetitions were more frequent in the visual than in the proprioceptive task \( F(33) = 8.133, P < 0.01 \), but no interaction group by task was found \( F(33) < 1 \).

The errors of the controls were too few to be considered in a qualitative analysis. The taxonomy of wrong responses of L/pts and R/pts in the two experimental conditions is detailed in Table 3.

Given that the overall performance of the two patient groups did not differ in the two testing conditions, wrong responses in the imitation and proprioceptive tasks were lumped together in the qualitative analysis. Responses ‘other’ were excluded from further analysis. Postural, apraxic and mixed responses were entered in a 2 (groups) × 3 (types of wrong response) analysis of variance that revealed a main effect of wrong response type \( F(2,66) = 77.9, P < 0.001 \) but no group effect \( F(1,33) = 1.18, \text{n.s.} \). The postural responses \( \text{mean} = 15.7 \) were more frequent than the apraxic \( \text{mean} = 3.9 \) and mixed \( \text{mean} = 4.2 \) in both groups. The interaction group × wrong response type was also significant \( F(2,66) = 9.97, P < 0.001 \). As shown in Fig. 1, postural responses were more frequent in R/pts than in L/pts (mean 20.1 versus 13.5) while apraxic and mixed responses were more frequent in L/pts than in R/pts (mean 5.5 versus 0.9 and 5.8 versus 1.1, respectively). The three R/pts showing signs of visuomotor
Table 1 Error types qualifying the postural reactions, as well as the apraxic, ambiguous or ‘other’ error classes considered in the study

<table>
<thead>
<tr>
<th>Postural instability reactions</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>Dorsal kyphosis</td>
<td>Maintaining sitting position by pressing thighs onto seat and rotating pelvis backward</td>
</tr>
<tr>
<td>Motion range loss</td>
<td>Movement with reduced joint amplitude</td>
</tr>
<tr>
<td>Asymmetrical execution</td>
<td>Lack of synergic contraction of the trunk muscles in the paretic side</td>
</tr>
<tr>
<td>Asymmetrical weight-bearing</td>
<td>Weight-bearing asymmetry during execution &gt;10% of the patient’s body weight</td>
</tr>
<tr>
<td>Non-paretic arm support</td>
<td>Use of non-paretic arm to hold onto the seat or to grip its edge</td>
</tr>
<tr>
<td>Non-paretic leg support</td>
<td>Widened stance, non-paretic foot pressed down to sustain weight and help balance</td>
</tr>
<tr>
<td>Additional movement</td>
<td>Bio-mechanically functional additional movements</td>
</tr>
</tbody>
</table>

Apraxic errors

<table>
<thead>
<tr>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perseveration</td>
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<tr>
<td>Superfluous movement</td>
</tr>
<tr>
<td>Substitution</td>
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<tr>
<td>Augmentation</td>
</tr>
</tbody>
</table>

Ambiguous or ‘other’ errors

<table>
<thead>
<tr>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Omission</td>
</tr>
<tr>
<td>Fragmentation</td>
</tr>
<tr>
<td>Use of paretic hand</td>
</tr>
<tr>
<td>Delay</td>
</tr>
<tr>
<td>Mirror movement</td>
</tr>
<tr>
<td>No action</td>
</tr>
</tbody>
</table>

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Table 2 Accuracy score and number of repetitions achieved by the three groups entering the study

<table>
<thead>
<tr>
<th></th>
<th>Visual task</th>
<th>Proprioceptive task</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Accuracy score (0–21)</td>
<td>No. of repetitions (42–0)</td>
</tr>
<tr>
<td>Controls (n = 30)</td>
<td>20.9 (0.36)</td>
<td>2.5 (2.30)</td>
</tr>
<tr>
<td>L/pts (n = 23)</td>
<td>7.96 (5.88)</td>
<td>28.09 (10.37)</td>
</tr>
<tr>
<td>R/pts (n = 12)</td>
<td>9.08 (5.63)</td>
<td>11–0 (1.0)</td>
</tr>
</tbody>
</table>

Data show means, SDs (in parentheses) and ranges.

Table 3 Frequency of wrong responses made by the two groups of patients in the two experimental conditions across error classes

<table>
<thead>
<tr>
<th>Wrong responses</th>
<th>L/pts (n = 23)</th>
<th>R/pts (n = 12)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Visual task</td>
<td>Proprioceptive task</td>
</tr>
<tr>
<td>Postural</td>
<td>6.8 (4.4)</td>
<td>6.7 (4.2)</td>
</tr>
<tr>
<td>Apraxic</td>
<td>2.7 (3.2)</td>
<td>2.8 (3.9)</td>
</tr>
<tr>
<td>Mixed</td>
<td>3.1 (3.8)</td>
<td>2.7 (2.9)</td>
</tr>
<tr>
<td>Other</td>
<td>0.4 (1.0)</td>
<td>0.3 (1.1)</td>
</tr>
</tbody>
</table>

Data show mean and standard deviation (in parenthesis).
The findings so far would speak for the independence of postural and apraxic responses resulting from two distinct mechanisms, one responsible for postural control, and the other for the goal-directed control of trunk movements. Dissociating performances within the group of L/pts would support such a claim (Dunn and Kirsner, 2003). L/pt 12 and L/pt 16 produced only 1 and 2 postural responses, respectively, but both produced 21 apraxic and 12 mixed responses. Contrarily, L/pt 3 and L/pt 4 produced 33 and 30 postural responses, but L/pt 3 produced no apraxic responses and only nine mixed responses while L/pt 4 produced no other wrong response.

A caveat is worth addressing. Postural responses may disguise underneath apraxic errors that would account for the lack of apraxic responses in R/pts who show predominant postural responses. In patients with trunk apraxia, apraxic responses would emerge only whenever postural responses did not conceal them. If this were the case, mixed responses would be very improbable. However, mixed responses were observed and sometimes different classes of responses were equipoise. L/pt 14 produced 11 postural, 11 apraxic and 14 mixed responses. Similarly, L/pt 11 showed numerous postural responses (14 out of 42) coupled with a similar number of apraxic (17) and mixed (10) responses. Both cases indicate that apraxic responses can be observed even within the context of postural compensatory movements. Moreover, postural difficulties were not predictive of the number of apraxic responses. The contrast between the pattern of L/pt 11 (above) and L/pt 5 and R/pt 7 who produced, respectively, 20 and 18 postural responses but no apraxic ones, suggests that the two systems giving rise to the two types of responses are independent of one another.

All considered, the data support the view that the different performance profile of the L/pts and R/pts would result from two different deficits hampering trunk movements: postural control impairment and apraxia. In turn, these two deficits would reflect the functioning of two independent processing components of the motor control system, one (praxic) centred on the left hemisphere, the other (postural) mainly calling for right-hemisphere functions. However, the right/left difference could have emerged from reasons other than hemispheric specialization. It has been stated in the Introduction that difficulties with trunk movements have been reported associated with gait apraxia following anterior brain lesion. It is therefore necessary to rule out the possibility that a specific intra-hemispheric site of the lesions, i.e. anterior versus posterior, plays a causal role, independently of the damaged hemisphere. Hence, postural and apraxic responses were analysed dichotomizing the sample of patients in two different groupings. One group encompassed the 13 patients whose lesion encroached upon the frontal lobes, while the other group included the 22 patients with posterior lesions sparing the frontal lobes. The mean number of postural, apraxic and mixed responses was similar in these two subgroups, respectively 17.7, 4.8 and 7.4 in the frontal lobe patients and 14.6, 3.4 and 2.3 in the non-frontal lobe patients. It appears at face value that the frontal lobe patients produced slightly more wrong responses across all types, indicating that the presence or absence of frontal lesion is irrelevant in the emerging of the hemisphere lesion/type of response interaction shown in Fig. 1.

Each wrong response could be characterized by more than one error type. Individual errors subdivided according to the taxonomy illustrated in Table 1 were recorded. Table 4 details the percentage of error types made by the two groups of patients in the two experimental conditions.

Postural and apraxic errors were entered in a 2 (groups) X 2 (error type) analysis of variance. The two groups did not differ in number of errors [F(33) < 1]: mean 18.7 and 18.5, respectively. Overall postural instability reactions (mean 28.7) were significantly more frequent [F(1,33) = 31.63, P < 0.001] than apraxic errors (mean 8.6). The interaction group X error type was also significant [F(1,33) = 6.71, P < 0.02]. Postural instability reactions were more frequent among R/pts (mean 35.6) than among L/pts (25.0). In contrast, L/pts (mean 1.4) committed more apraxic errors than R/pts (mean 1.3).

Non-parametric correlative analyses were run between the total number (sum of two testing conditions) of postural and apraxic errors committed by each L/pt and their scores in the two tests assessing language (Token Test) and ideomotor apraxia (gesture imitation test). Postural instability reactions correlated with neither test (Spearman’s rho 0.077 and 0.191, respectively). On the contrary, apraxic errors showed a negative correlation with both the Token Test (Spearman’s rho −0.456, P < 0.05) and ideomotor apraxia scores (Spearman’s rho −0.631, P < 0.005). However, clear dissociating performances between limb and trunk apraxia were observed in single individuals. For example, L/pt 20 scored 31 out of 72 in the limb ideomotor apraxia test (cut-off 53; De Renzi et al., 1982), yet he produced only three apraxic and two mixed out of a total of 19 out of 42 wrong responses.
in the trunk items. Case L/pt 15 showed the opposite pattern; he performed near ceiling in the limb apraxia test (70 out of 72), though producing 12 apraxic and 13 mixed wrong responses in the trunk battery out of a total of 29 out of 42 wrong responses. The contrasting profiles of these two patients demonstrate that limb and trunk apraxia can be thought of as double dissociated (Cubelli, 2003).

It is also worth considering in some detail the performance of other individual patients, in relation to their neurological examination. Four L/pts and 1 R/pt did not show any limb strength or sensory deficits, scoring 0 in the standardized neurological examination (Bisiach et al., 1986). Their aggregated proportion of the different types of wrong responses in the visual and proprioceptive conditions is laid out in Table 5. Three of these patients (L/pt 3, L/pt 6 and R/pt 6) presented with an overwhelming number of postural responses. Another participant (L/pt 16) showed the opposite pattern and her responses were mainly apraxic, while the remaining one (L/pt 17) showed no difference between the two main response classes. This indicates that no pattern of errors hampering the patients’ performance can be entirely dependent on their motor or sensory status.

The scores obtained in the two sessions by the patients re-tested are laid out in Table 6. The distribution of response types proved to be consistent enough across the two testing sessions.

### Table 4

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<td>5.4</td>
</tr>
<tr>
<td>Asymmetrical execution</td>
<td>7.0</td>
<td>12.0</td>
</tr>
<tr>
<td>Asymmetrical weight-bearing</td>
<td>28.3</td>
<td>31.4</td>
</tr>
<tr>
<td>Non-paretic arm support</td>
<td>1.7</td>
<td>7.0</td>
</tr>
<tr>
<td>Non-paretic leg support</td>
<td>2.6</td>
<td>7.0</td>
</tr>
<tr>
<td>Additional movement</td>
<td>10.3</td>
<td>12.4</td>
</tr>
<tr>
<td>Total postural instability reactions</td>
<td>65.5</td>
<td>94.5</td>
</tr>
<tr>
<td>Apraxic errors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perseveration</td>
<td>13.1</td>
<td>3.3</td>
</tr>
<tr>
<td>Superfluous movement</td>
<td>9.2</td>
<td>1.6</td>
</tr>
<tr>
<td>Substitution</td>
<td>7.0</td>
<td>0.5</td>
</tr>
<tr>
<td>Augmentation</td>
<td>1.1</td>
<td>1.1</td>
</tr>
<tr>
<td>Total apraxic errors</td>
<td>32.25</td>
<td>3.35</td>
</tr>
<tr>
<td>Other errors</td>
<td>4.4</td>
<td>2.5</td>
</tr>
<tr>
<td>Total other errors</td>
<td>2.65</td>
<td>1.95</td>
</tr>
</tbody>
</table>

### Table 5

<table>
<thead>
<tr>
<th>Case no.</th>
<th>Total no. (and %) of wrong responses</th>
<th>Response type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Postural</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L/pt 3</td>
<td>42 (1.0)</td>
<td>33 (0.79)</td>
</tr>
<tr>
<td>L/pt 6</td>
<td>12 (0.29)</td>
<td>8 (0.67)</td>
</tr>
<tr>
<td>L/pt 16</td>
<td>35 (0.83)</td>
<td>2 (0.06)</td>
</tr>
<tr>
<td>L/pt 17</td>
<td>20 (0.48)</td>
<td>10 (0.50)</td>
</tr>
<tr>
<td>R/pt 6</td>
<td>25 (0.60)</td>
<td>24 (0.96)</td>
</tr>
</tbody>
</table>

The performances from the two experimental conditions have been added (total score range 0–42).
of asymmetrical weight-bearing towards the non-paretic side in L/pts could be interpreted as reflecting attempts of postural adjustments.

**Discussion**

The aim of the study was to investigate the relative independence and the association with lesion side of two kinds of errors hampering trunk movements, namely apraxia and postural instability. Using a classic, old-fashioned approach of ‘group by hemisphere’ study, we demonstrated a clear difference in the kind of errors that brain damaged patients commit when carrying out a trunk movement according to the side of their lesion. As typical of most studies on apraxia, we used a clinical test that allowed us to detect errors and qualify their characteristics. Apraxic responses (i.e. execution errors not due to biomechanical constraints, see Table 1) were overwhelming within the patients with left-hemisphere lesions (L/pts). On the contrary, postural instability reactions (i.e. compensations to overcome stability or asymmetry deficits, see Table 1) were significantly more frequent among the patients with right-sided lesions (R/pts).

The lack of difference between the two groups in terms of presence and severity of limb paresis or sensory deficits makes it unlikely that the observed higher frequency of postural instability reactions in R/pts could be traced back to a differential trunk weakness between the groups. Moreover, the observed asymmetry cannot be accounted for by invoking a different number of anterior lesions in one group than in the other (see e.g. Nutt et al., 1993). Indeed, the presence or absence of frontal lobe lesions had little effect on the type of errors produced in performing trunk movements. Finally, although the occurrence of trunk apraxia correlates with the presence of limb apraxia and with aphasia, dissociating cases suggest that it has to be conceived as distinct from either deficit.

In the Introduction we summarized the accrued evidence suggesting a link between right hemisphere and postural control, and between left hemisphere and the praxis system. Consistently, our findings indicate that faulty trunk movements are frequent in brain damaged patients and can be due to the derangement of either cognitive system, respectively due to lesions in the right or left hemisphere.

While there is general agreement that the cerebral cortex, in particular that of the left hemisphere, plays a major role in praxis control, the hypothesis that postural control is at least partly organized within the cerebral cortex is still relatively new (see reviews in Massion, 1998; Pérennou et al., 1999). However, a number of findings support the hypothesis: lesion studies in animals demonstrated the link between cortical damage and postural unbalance (e.g. Loffe, 1997); anticipatory postural adjustments are altered also by pure cortical lesions in humans (Palmer et al., 1996); the response latencies (over 100 ms) to postural instability are far too slow to be pure spinal reflexes (e.g. Nashner and McCollum, 1985); cortical magnetic stimulation slows down postural adjustments (e.g. Palmer et al., 1994). Indeed, early clinical observations by Held and colleagues, Wade and colleagues and Bohannon and colleagues hinted that not only is postural control partly organized within the cortex, but its organization is also lateralized (Held et al., 1975; Wade et al., 1984; Bohannon et al., 1986). They found that patients with right-hemisphere lesions had greater troubles than those with left-hemisphere lesions in regaining the ability to stay seated unassisted. These clinical observations have been supported by a series of experimental studies using force plates (Hesse et al., 1994; Rode et al., 1997). The results from these studies converge in showing that the typical findings of a weaker pressure of the paretic leg, the increased oscillations and the reduced stability are greater after right- than after left-hemisphere lesion. The authors interpreted their findings calling upon the role of the right hemisphere in processing spatial information.

The association of postural compensatory responses and right-sided lesions in trunk movements reported in studies using force plates and in our findings echoes the differential disruption of spatial and verbal secondary tasks on postural stability reported with healthy volunteers in the experimental psychology literature. For example, Kerr and colleagues demonstrated that the concomitant performance of a visuo-spatial (right-hemisphere) memory task would interfere with
maintaining a difficult posture more than a verbal (left-hemisphere) memory task (Kerr et al., 1985). Similarly, Maylor and colleagues (e.g. Maylor and Wing, 1996; Maylor et al., 2001) showed that postural stability problems due to old age are further increased by additional cognitive demands, and that the degree of interference was greater when postural stability tasks were coupled with visuospatial tests rather than verbal tasks in a dual-task paradigm.

Pérennou and colleagues reported a high correlation between the number of omitted targets in a cancellation task and postural stability measured with a 12-item clinical scale, and introduced the concept of ‘postural neglect’ to account for the association between right-hemisphere lesions and postural deficits (Pérennou et al., 1999). Yet, in the current study postural deficits were observed in the absence of visuoperceptual neglect. The concept of (trunk) postural neglect may carry some explanatory power without conceiving neglect as a unitary deficit of a monolithic function. Neglect is generally defined in terms of asymmetrical performance. Asymmetrical weight-bearing, which was the most frequent postural error in the current study (see Table 4), in particular towards the paretic side (75.3% and 50.4% in R/pts and L/pts, respectively), can be thought of as an expression of neglect involving body postures. It is worth noticing that body-centred (egocentric) coordinates are critical in the pattern of manifestations of spatial neglect following right-hemisphere lesions (Driver et al., 1994; see reviews by Walker, 1995; Umilta, 2001; Cubelli and Speri, 2001). In particular, trunk-centred coordinates proved to be the most relevant frame of reference in eliciting extra-personal neglect in R/pts (e.g. Beschin et al., 1997). Taken together the evidence suggests that a system sitting in the right hemisphere plays a major role in the processing of trunk postures.

Gurfinkel and colleagues maintained that a system specifically coding body posture representations should exist (Gurfinkel et al., 1988). Recent models of postural organization include a representational level that would allow us to process the body’s configurations in relation to the environment (see e.g. Massion, 1998). Gallagher (1995) recommended that such a system should refer to a non-conscious control device. It is intriguing to posit that this postural system contributes to coding the environment in terms of left and right space, interacts with the mechanisms of space exploration, and is more lateralized to the right side of the brain. We suggest that postural wrong responses are more frequent following right than left-hemisphere lesion because of possible damage to this postural representational system. This system would be preferentially located in the right hemisphere, though L/pts also showed postural instability reactions in complying with the requirements of the present experiment: hence the right dominance for postural control ought to be thought of as relative rather than absolute. The automatic adjustments of trunk balance, regulated mainly by the right hemisphere, are the basis upon which intentional movements are organized and executed, mainly under the control of the left hemisphere (see also Massion, 1998).

To sum up, we have demonstrated that disturbances in trunk movements shown by patients suffering from stroke sequelae can be due to different reasons, including praxis or postural problems, which in turn are predominantly associated with left- and right-hemisphere lesions, respectively. These findings should be kept in mind when evaluating trunk movement difficulties shown by stroke patients, in following up their recovery or when tailoring rehabilitation programmes.

Acknowledgements

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References


Appendix I

Meaningless movements
Neck flexion
Left lateral flexion of neck
Neck extension
Right trunk rotation
Trunk flexion
Right lateral flexion of neck
Left lateral flexion of trunk
Trunk extension
Right neck rotation
Left trunk rotation
Left neck rotation
Right lateral flexion of trunk

Symbolic movements
Nod with head – twice
Make a bow
Shake head (meaning ‘no’)
Shrug shoulders
Come to attention (sitting)

Reaching movements
Grasp a small wooden cylinder placed at 45° in the ipsilesional space in reaching distance with the unimpaired hand
Grasp a small wooden cylinder placed at 45° in the contralesional space in reaching distance with the unimpaired hand
Grasp a small wooden cylinder placed at 45° in the ipsilesional space 15 cm beyond reaching distance with the unimpaired hand
Grasp a small wooden cylinder placed at 45° in the contralesional space 15 cm beyond reaching distance with the unimpaired hand


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