Speed of information processing

Speed of information processing in the subacute stage after stroke was studied in 88 first-ever, unilateral ischemic stroke patients. The patient group included 42 right and 46 left hemisphere patients. Seventy-one control subjects were also examined. Four reaction time tasks with different levels of complexity were used: two visuomotor, and two semantic categorisation tasks. The results showed that stroke causes a decrease in decision making speed, but that the effect is different for right and left hemisphere patients. The right hemisphere patients were slower than the control group on all reaction time tasks, and slower than the left hemisphere patients on the visuomotor tasks. The left hemisphere patients were slower than the healthy controls, only on the most complex tasks, the categorisation tasks.

Speed of information processing after unilateral stroke.


Introduction

In the last decade it has become increasingly clear that stroke not only leads to specific cognitive deficits such as aphasia, apraxia and neglect, but also affects general cognitive functions such as memory, intelligence and attention (Hochstenbach, Mulder, van Limbeek, Donders, & Schoonderwaldt, 1998; Hom & Reitan, 1990; Sundet, Finset, & Reinvang, 1988; Tattemichi, Desmond, Stern, Paik, & Bagiella, 1994). Existing studies of general cognitive functioning after stroke have not included objective measurements of mental speed, but rather have derived conclusions indirectly from other measures. However, speed of information processing is known to influence performance on other cognitive tasks like complex tasks of intellectual performance (Salthouse, 1996; Schretlen, et al., 2000). For a clear understanding of cognitive dysfunctioning after stroke, it is therefore necessary to understand the effect of stroke on speed of information processing. This is the main goal of this study.

Subjective data on changes after stroke showed that patients and their relatives rated mental slowness first on a list of cognitive complaints (Hochstenbach, 1999; Visser-Keizer, Meyboom-de Jong, Deelman, Berg, & Gerritsen, 2002). Reaction time experiments, preferably tasks which split reaction time into a movement and a decision component, are the most generally accepted objective way to study mental speed (van Zomeren & Brouwer, 1994). Studies, mainly in the field of closed head injury research, have indicated the presence of a so-called ‘complexity-effect’. This means that, compared to healthy subjects, decision times of patients increase disproportionally as the level of complexity of the task increases (Miller, 1970; van Zomeren & Deelman, 1976). The complexity effect has not explicitly been studied in stroke patients, but there have been several studies examining this effect in patients with unilateral cerebral disease of various aetiologies (Dee & van Allen, 1971, 1973; Howes & Boller, 1975; Tartaglione, et al., 1991).

Comparing reaction times on a simple auditory task and a visual two-choice reaction time task, Dee and van Allen (1971) concluded that choice reaction time was no more sensitive to the effects of cerebral disease than simple reaction time. However, they did find a difference between left and right hemisphere patients. Although both patient groups had longer reaction times than the control subjects on the choice tasks, only the right hemisphere patients were slower than the control group in the simple reaction time task. The finding that right hemisphere damage might be especially detrimental to simple reaction time is consistent with the results of Howes and Boller’s study (1975). Using a simple auditory reaction time task, they found that both left and right hemisphere patients had increased reaction times, but that the effect was much stronger in the right hemisphere group (Howes & Boller, 1975).

In a subsequent study, Dee and van Allen (1973) extended their experiments, and used a 1-, 2-, 3-, and 4-choice visual reaction time task. The stimuli consisted of
coloured lights, and subjects had to respond by pressing a button of the corresponding colour with the ipsilateral hand. They compared the decision times of 16 patients with left hemisphere damage, 16 patients with right hemisphere damage and 16 control subjects. Both patient groups were slower than the control group, but left hemisphere patients showed a complexity effect, while right hemisphere patients did not. Tartaglione and colleagues (1991) used a four-choice reaction time task, comparable to the four-choice condition in the Dee and van Allen experiment. They also found that left hemisphere patients were more impaired in the decision making process than right hemisphere patients. However only the accuracy of the responses was affected, not the reaction times; left hemisphere patients made more mistakes, but were not slower than right hemisphere patients.

There has been some research investigating mental speed after unilateral stroke using simple or complex reaction time tasks. However, few researchers have investigated both simple and complex reaction times. Studies using a simple reaction time task found right hemisphere patients to be slower than left hemisphere patients and control subjects (Coslett, Bowers, & Heilman, 1987; Egelko, et al., 1989; Kaizer, Korner-Bitensky, Mayo, Becker, & Coopersmith, 1988). Riege and colleagues (1982) used a more complex task, recording reaction time with a voice-activated clock. Subjects had to decide whether they had seen a stimulus before or not. Left hemisphere patients appeared to be slower than control subjects and right hemisphere patients, and had a strong negative decision bias, making few false positive, but many false negative mistakes (Riege, Klane, Metter, & Hanson, 1982).

When studying general cognitive deficits in stroke patients, the role of specific cognitive disorders like aphasia and neglect must be taken into account. The influence of aphasia on reaction time is not entirely clear. Korda and Douglas (1997) found that aphasics had impaired attentional capacity, reflected in slower reaction times and a complexity effect, than a group of non-brain damaged orthopaedic patients. Yet, like several other investigators, they found no significant correlation between severity of comprehension deficits and attentional capacity (Kaizer, et al., 1988; Riege, et al., 1982). It is, however, rather clear that reaction times are increased by neglect or hemianopia. This is true not only for stimuli presented in the left and central visual fields (Kaizer, et al., 1988), but also for stimuli presented ipsilateral to the lesion in the right visual field (Egelko, et al., 1989) or auditory space (Samuelsson, Hjelmquist, Jensen, Ekholm, & Blomstrand, 1998).

In the present study unilateral, first ever, ischemic stroke patients in the subacute stage were assessed with a reaction time battery consisting of a simple reaction time task, an eight choice visuomotor reaction time task, and two more complex cognitive reaction time tasks, one verbal and one non-verbal. The visuomotor stimuli were equally divided over the ipsilateral and contralateral visual fields. All patients were required to respond with their ipsilateral hand. The healthy
control subjects were randomly divided into a group responding with the left hand and a group responding with the right hand, regardless of their hand-dominance.

In analysing the data we will first analyse the performance of the healthy subjects on the reaction time tasks. We will analyse the effects on decision time and motor time of task-difficulty, task modality (verbal versus non-verbal), and the use of the dominant versus the non-dominant hand. The effects of age, education and gender will also be established. With this knowledge we can answer the following questions about the differences in decision and movement times between the control, the right hemisphere and the left hemisphere groups: [a] Are there complexity-effects? [b] Are decisions on stimuli presented in the visual field contralateral to the side of the lesion slower than ipsilesional decisions? [c] Are there differences in accuracy between the groups? [d] What is the influence of aphasia and neglect on the decision times?

Methods

Subjects

First-ever, unilateral, ischemic stroke patients were recruited through 350 general practitioners (GPs) and the stroke unit of the University Hospital in Groningen, in order to examine a community-based group of stroke patients. The GPs and the stroke unit presented 235 stroke patients. Neurological and GPs’ reports were checked. Patients who did not meet the criterion of having had a first ever, unilateral, ischemic stroke (n = 45) were excluded. Since examining a representative group of stroke patients was an important aim of this study, patients with aphasia were, in principle, included. Only those patients who had such severe language deficits that they were unable to understand even the simplest test instructions were excluded (n = 7). Patients with other neurological disorders, psychiatric diseases, or alcohol abuse were also excluded (n = 13). Several patients were too weak to be tested (n = 16), died before testing (n = 3), or could not be reached (n = 6). Finally, a number of patients did not want to participate in the study (n = 57). Of the 235 stroke patients, 88 were finally included in this study. The group consisted of 58 men and 30 women. Mean age was 65.4 years (range: 39-93, sd = 11.3) and mean educational level was 3.9 (range 1-7, sd = 1.3). Educational level was scored on a 7-point scale, ranging from 1, less than 6 years of education, to 7, university degree (Verhage, 1964). First neuropsychological assessment took place at a mean of 133 days post stroke (range: 72-233 days, sd = 31 days).

The patient-group was divided into a group with right hemisphere lesions (RH-patients, n = 42) and a group with lesions in the left side of the brain (LH-patients, n = 46). The two patient groups did not differ in age (t = -.390, p = .70), education (Z = -.059, p = .95) or gender ($\chi^2 = .350, p = .55$).

Seventy-one age-peers (40 male and 31 female) without neurological or psychiatric disorders were recruited from the practices of four GPs. Mean age in
this group was 65.9 years (range: 41-87, sd = 11.8) and mean educational level was 4.1 (range 1-7, sd = 1.5). Statistical testing revealed no differences between the patient and control group with respect to age ($t = .251, p = .80$), education ($Z = -.762, p = .45$) or gender ($\chi^2 = 1.52, p = .217$).

Procedure and materials

The present study is part of a larger longitudinal investigation in which an extensive neuropsychological test-battery is used to investigate cognitive functioning after stroke. The battery took about four hours for each subject and was administered in two sessions. The first session took place at the participant’s home; the second at the University Hospital in Groningen. Participants who were not able to come to the hospital for the second visit were again tested at home. Only those tests that are relevant for this report will be discussed here.

Reaction time tasks

Reaction times were measured using a device constructed according to a model developed by van Zomeren (1981). It consisted of eight stimulus lights in a semicircular array and one central button equidistant from each of the stimulus lights. The computer program was designed to register decision and movement times in milliseconds. Subjects pressed the central button until a stimulus appeared, then released the central button (decision time) and pressed the target button (movement time). Patients used the hand ipsilateral to the side of the lesion whenever this was possible. Orthopaedic problems prevented three right hemisphere patients and one left hemisphere patient from using their ipsilateral hand, but they appeared to be capable of using their contralateral hand. In the patient group, 40 subjects used their right hand and 48 subjects used their left hand. Four of the subjects who used their right hand were left handed. One of the subjects who used their left hand was left-handed. The control subjects were randomly divided into a group using the right hand (N=35), and a group using the left hand (N=36). Three of the subjects who used their right hand were left handed. Five of the subjects who used their left hand were left handed. Although the terms ipsilateral and contralateral have no meaning in the healthy subjects, the hand used to respond will be called the ipsilateral hand when patients and controls are compared. In all conditions participants were instructed to respond as fast as possible. Only the decision and movement times of the correct answers are included in the statistical analyses. Median decision times and movement times are used to attenuate the influence of incidental extreme values.

Reaction time tasks: visuomotor reaction time

1. Simple reaction time task (RT1). In this task one of the eight lights was defined as the target stimulus. The task consisted of two subtests, with a warning in between. For the right hemisphere patients, the light located furthest to the right served as the target for the first 14 trials, while the light located furthest to the left
served as the target for the second 14 trials. For the left hemisphere patients this sequence was reversed. In order not to frustrate slow patients who might not be able to manage rapidly presented stimuli, the inter-stimulus intervals were measured from the time the central button was pressed again, and varied randomly between 2 and 5 seconds.

2. **Eight-choice reaction time task (RT8).** In this task each of the eight stimulus lights functioned as target seven times (56 trials). The order of presentation of the stimuli was random. Responses to the stimuli situated on the left and right half of the semicircular array were registered separately. Inter-stimulus intervals were the same as in the RT1.

**Reaction time tasks: cognitive reaction time**

For the cognitive reaction time tasks, a computer screen was placed behind the reaction time apparatus, so that it was clearly visible to the participant. Six of the stimulus lights were covered, and the two lights situated on the side of the used hand were defined as a ‘yes’ and a ‘no’ button and were labelled ‘yes’ and ‘no’, to reduce the demand on the subject’s memory. Stimulus intervals were fixed at 2 seconds from the time the central button was pressed.

3. **Categorisation of words (Text-task).** A word representing a category, for example: ‘colours’, was presented on the upper half of the computer screen. Subsequently a stimulus word, for example: ‘red’, appeared on the lower half of the screen. The subject had to decide whether red is a colour or not, then press the ‘yes’ or the ‘no’ button. Each category word remained on the screen for twelve consecutive stimulus words. Half of the stimulus words belonged to the category and half did not. Stimuli which did and did not belong to the category were presented in random order. The test began with the presentation of two practice category words, each with six stimulus items. The actual test consisted of four category words. Changes in category were indicated by a warning signal. No ambiguous items were included in the test.

4. **Landscape ‘categorisation’ (Picture-task).** This task is a non-verbal variant of the Text-task. It was designed to eliminate the effect of difficulty reading and / or understanding words on task performance. The procedure was the same, but the stimulus material was different. Instead of words, pictures of landscapes, for example a farm, were used to specify the category. The stimuli were also pictures, for example, a cow. Subjects had to decide whether the pictures fitted into the landscape or not. The test consisted only of familiar items that were selected after a pilot study.
Language assessment

[A] Language was tested using two subtests, Word comprehension (1) and Sentence comprehension (2), from a Dutch aphasia test battery (Deelman, Koning-Haanstra, Liebrand, & van de Burg, 1981) and a 40-item naming task (3) (Butter, Berg, Deelman, & Maring, 1988). For the SAN-subtests the cut-off scores according to the manual were used. The cut-off score for the naming task was set at two standard deviations below the mean score in the control group.

[B] About a week before neuropsychological testing took place, language deficits were clinically assessed by a neuropsychologist, who interviewed the subjects for one and a half hours. Both expressive and receptive skills were scored. A language deficit could be absent (score 0), mild (score 1), or severe (score 2).

The patients were classified as aphasic or non-aphasic on the basis of the three test scores and the two observation scores. Combining the five scores led to a minimum score of zero and a maximum score of 7. Every patient with a sum score of two or higher was classified as aphasic. According to this definition there were five aphasic right hemisphere patients (12%), and 15 aphasic left hemisphere patients (36%).

Neglect assessment

[A] The Star-cancellation test (1), a subtest from the Behavioural Inattention Test (BIT), was administered as a screening tool for neglect (Wilson, Cockburn, & Halligan, 1987). The cut-off score according to the BIT-manual was used. The Line bisection task (2) by Schenkenberg (1980) was also used to measure neglect. When possible subjects performed the test twice, once with the left hand and once with the right hand. The deviation from the true centres of the lines and the number of omissions were scored. Following the literature, a deviation of 10% or an omission of more than two lines, were used as cut-off scores indicating the presence of neglect (van Deusen, 1984; Schenkenberg, Bradford, & Ajax, 1980; Soukup, Harrell, & Clark, 1994).

[B] Neglect was also assessed clinically by the neuropsychologist who interviewed the subjects. Neglect was qualified as absent (score 0), mild (score 1) or severe (score 2). The combined test scores and the observation scores were used to identify patients with neglect. Combining the four scores led to a minimum score of zero and a maximum score of 5. A sum score of two or higher, omissions mainly in the contralateral visual field and deviations to the side ipsilateral to the lesion were the basis for the classification of neglect. Eight right hemisphere patients (19%) and one left hemisphere patient (2%) showed neglect according to this definition.
Results

Healthy subjects

The first question concerning the performance of the healthy subjects was whether there was an effect of the complexity of the task on the decision times. The RT8 was expected to be more difficult than the RT1, and both cognitive tasks, combined in one score, were supposed to be more complex than the combined visuomotor tasks. The decision and movement times on the visuomotor reaction time tasks, the categorisation tasks, and the combined visuomotor and cognitive tasks are presented in figure 1.

As expected, paired t-tests revealed significantly slower decision times ($t = -8.73$, $p < .01$), but not movement times ($t = -.001$, $p = .99$) on the RT8 in comparison with the RT1. Comparison of the visuomotor and the cognitive reaction time tasks showed that both the decision ($t = -15.91$, $p < .01$) and the movement ($t = -8.09$, $p < .01$) time were faster for the visuomotor stimuli than for the cognitive stimuli. To determine whether decision time and movement time represent different aspects of reaction time, we performed a principal components analysis (varimax rotated). Three underlying factors were found that accounted for 87% of the total variance. Conceptually these factors could be identified as a factor ‘movement time’ (Eigenvalue = 6.47) and two decision time factors: ‘visuomotor decision time’ (Eigenvalue = 2.45) and ‘cognitive decision time’ (Eigenvalue = 1.06). The movement times on the cognitive tasks loaded strong on the two factors ‘movement time’ (Text = .70, Picture = .66), and ‘cognitive decision time’ (.54, and .55 respectively). Our main focus in the analyses of the patients’ data will remain, however, on the decision times.

The second question concerned the difference in the speed of processing verbal and non-verbal visual information. Testing revealed that the processing of
non-verbal material was more time consuming than the processing of verbal information \((t = -5.06, p < .01)\). The same was true for the movement times \((t = -5.46, p < .01)\).

The third question involved the effect of the use of the preferred or the non-preferred hand. The right handed subjects using their left hand were compared to the right handed subjects using their right hand. One way ANOVA showed no differences in movement or decision times between the two groups on any reaction time task.

Finally we looked at the influence of the variables age, level of education and gender. All decision times were correlated with age, with stronger correlations for the more difficult tasks. Education was related to the cognitive decision times, but not to the visuomotor tasks (see table 1). There was no effect of gender (t-tests).

Table 1: Correlations (Spearman) between decision times, and age and education level in the control subjects

<table>
<thead>
<tr>
<th>Decision times:</th>
<th>RT1</th>
<th>RT8</th>
<th>Text</th>
<th>Picture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>.30*</td>
<td>.36**</td>
<td>.50**</td>
<td>.70**</td>
</tr>
<tr>
<td>Education</td>
<td>.08</td>
<td>-.08</td>
<td>-.38**</td>
<td>-.39**</td>
</tr>
</tbody>
</table>

* \(p < .05\), ** \(p < .001\).

\(RT1=\text{simple choice task}, RT8=\text{eight choice task}, Text=\text{text categorisation task}, \text{and Picture}=\text{landscape ‘categorisation’ task}\)

In sum, the reaction time tasks appeared to have different levels of complexity; the RT8 was more difficult than the RT1, both of cognitive tasks were more difficult than the visuomotor tasks, and the Picture-task was more difficult than the Text-task. Though the difficulty is reflected in the decision times and partly in the movement times, decision and movement times do appear to measure different aspects of reaction time. The use of the dominant versus the non-dominant hand did not influence performance in the control group, an important precondition for comparing the control and the patient groups. Finally age and education were significantly related to the decision times. It is essential to remember that the two patient groups do not differ from the control group with respect to these two variables.
**Patients versus healthy subjects: movement times**

Since the main interest of this study is in the decision times, only the most important results of the movement time analysis will be summarised here (see figure 2, and table 2).

No main effects of group were found in a repeated measures analyses of variance of the visuomotor reaction time tasks (F(2,156)= 1.62, p= .22). The groups differed from each other only on the cognitive reaction time tasks (F(2,152)= 3.91, p= .02). The right and left hemisphere patients were slower than the controls (p= .03 and p= .02 respectively), but they did not differ from each other. The interaction between group and test, and between group and visual field did not reach significance in any of the tests.

Table 2: Mean median movement times, standard deviations, and the range of values for the control subjects, right hemisphere (RH), and left hemisphere (LH) patients.

<table>
<thead>
<tr>
<th>Task</th>
<th>Control Mean (sd)</th>
<th>Control Range</th>
<th>RH-patients Mean (sd)</th>
<th>RH-patients Range</th>
<th>LH-patients Mean (sd)</th>
<th>LH-patients Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>MT1-ipsi</td>
<td>322 (112)</td>
<td>120-642</td>
<td>354 (137)</td>
<td>134-663</td>
<td>346 (116)</td>
<td>172-682</td>
</tr>
<tr>
<td>MT1-contra</td>
<td>346 (118)</td>
<td>143-715</td>
<td>376 (134)</td>
<td>171-716</td>
<td>351 (120)</td>
<td>175-816</td>
</tr>
<tr>
<td>MT8-ipsi</td>
<td>320 (112)</td>
<td>149-718</td>
<td>365 (128)</td>
<td>174-666</td>
<td>350 (115)</td>
<td>175-717</td>
</tr>
<tr>
<td>MT8-contra</td>
<td>348 (116)</td>
<td>167-745</td>
<td>400 (144)</td>
<td>204-744</td>
<td>377 (119)</td>
<td>202-739</td>
</tr>
<tr>
<td>Text-MT</td>
<td>406 (132)</td>
<td>195-837</td>
<td>474 (162)</td>
<td>202-893</td>
<td>506 (226)</td>
<td>204-1569</td>
</tr>
<tr>
<td>Picture-MT</td>
<td>451 (157)</td>
<td>230-1076</td>
<td>525 (182)</td>
<td>245-1102</td>
<td>520 (163)</td>
<td>229-1127</td>
</tr>
</tbody>
</table>

Figure 2: Movement times. RT1=simple task, RT8=eight choice task, Text=text categorisation task, and Picture=landscape ‘categorisation’ task. Ipsi=stimuli presented in the visual field ipsilateral to the side of the lesion, contra= contralaterally presented stimuli.
Patients versus healthy subjects: decision times

The decision times of the three groups on the reaction time tasks are presented in figure 3, and table 3.

![Figure 3: Decision times.]

Table 3: Mean median decision times, standard deviations, and the range of values for the control subjects, right hemisphere (RH), and left hemisphere (LH) patients.

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>RH-patients</th>
<th>LH-patients</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M (sd)</td>
<td>range</td>
<td>M (sd)</td>
</tr>
<tr>
<td>DT1-ipsi</td>
<td>367 (86)</td>
<td>243-813</td>
<td>455 (170)</td>
</tr>
<tr>
<td>DT1-contra</td>
<td>332 (50)</td>
<td>247-558</td>
<td>414 (181)</td>
</tr>
<tr>
<td>DT8-ipsi</td>
<td>396 (56)</td>
<td>303-558</td>
<td>449 (83)</td>
</tr>
<tr>
<td>DT8-contra</td>
<td>408 (55)</td>
<td>325-562</td>
<td>635 (728)</td>
</tr>
<tr>
<td>Text-DT</td>
<td>819 (205)</td>
<td>536-1420</td>
<td>1082 (860)</td>
</tr>
<tr>
<td>Picture-DT</td>
<td>999 (427)</td>
<td>473-3159</td>
<td>1098 (386)</td>
</tr>
</tbody>
</table>

A. Visuomotor tasks. Repeated measures analysis revealed an overall main effect for group (F(2,16)= 7.76, p< .01) on the visuomotor tasks. Post hoc testing (LSD) showed that the right hemisphere patients were slower than both the left hemisphere patients (p=.01) and the control group ( p< .01). The left hemisphere patients were not slowed compared to the control group (p=.36). No main effect was found for the visual half field in which the stimuli were presented. The interaction between visual field and group, however, was significant (F( 2,16)= 3.05, p= .05): right hemisphere patients were slower on contralateral stimuli than were the left hemisphere patients and the control group. There was a main effect for difficulty (F(1,16)= 27.25, p< .01), the decision times on the RT8 being slower than on the RT1. Again a significant interaction was found between group and difficulty (F(2,16)= 3.07, p= .05): the right hemisphere group was significantly slower on the RT8. Finally there was a three-way interaction between visual field,
Speed of information processing

group and difficulty (F(2,156)= 3.11, p=.05). Right hemisphere patients were slowest on the RT8, and this effect was most pronounced in the contralateral visual field.

B. Cognitive tasks. Repeated measures analysis of variance showed a main effect of group (F(2,152)= 3.48, p=.03). Both right and left hemisphere patients were slower than controls (p=.05 and p=.02 respectively). Post-hoc testing showed no difference between the patient groups. The second main effect, modality (verbal versus non-verbal), was also significant (F(1,152)= 9.35, p<.01). Decision times on the non-verbal task were longer than on the verbal task. There was no significant interaction between group and modality.

C. Visuomotor versus cognitive tasks. Combined visuomotor and cognitive decision times for the three groups are presented in figure 4.

Figure 4: Visuomotor and cognitive decision times.

As follows logically from the earlier analyses, there was a significant main effect of group (F(2,152)=3.86, p=.02). Post-hoc testing showed that right hemisphere patients responded more slowly than the control group (p=.01). The same was true for the left hemisphere patients (p=.04). There was no difference between the patient groups. There was a main effect of difficulty (F(1,152)= 413.70, p<.01): the decision times were longer on the cognitive tasks. Most importantly the interaction between difficulty and group was significant (F(2,152)=3.43, p=.04): the left hemisphere patients were disproportionately slowed by the increased complexity of the task.
Patients versus healthy subjects: error rates

Neither of the groups made any errors—pressing the wrong light—on the visuomotor tasks. The number of errors made by the three groups on the cognitive tasks is presented in Table 4. Reactions were recorded as an error when the subject pressed ‘yes’ when it should be ‘no’, or vice versa.

Table 4: The mean number of errors made on the cognitive reaction time tasks.

<table>
<thead>
<tr>
<th>Lesion side</th>
<th>Text errors</th>
<th>range</th>
<th>Picture errors</th>
<th>range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right</td>
<td>1.8</td>
<td>0-22</td>
<td>1.9</td>
<td>0-8</td>
</tr>
<tr>
<td>no neglect</td>
<td>1.4</td>
<td>0-6</td>
<td>1.7</td>
<td>0-8</td>
</tr>
<tr>
<td>neglect</td>
<td>3.4</td>
<td>0-22</td>
<td>2.9</td>
<td>0-8</td>
</tr>
<tr>
<td>Left</td>
<td>3.0</td>
<td>0-25</td>
<td>2.2</td>
<td>0-11</td>
</tr>
<tr>
<td>all patients</td>
<td>1.8</td>
<td>0-16</td>
<td>2.0</td>
<td>0-11</td>
</tr>
<tr>
<td>no aphasia</td>
<td>5.6</td>
<td>0-25</td>
<td>2.8</td>
<td>1-7</td>
</tr>
<tr>
<td>aphasia</td>
<td>1.1</td>
<td>0-7</td>
<td>1.4</td>
<td>0-9</td>
</tr>
</tbody>
</table>

The differences in number of errors made by the three groups were tested with a non-parametric test (Mann-Whitney U). There were no significant differences between the right and left hemisphere patients, or between the right hemisphere patients and the control group. The differences between the left hemisphere patients and the control group were significant for both cognitive tasks (Text: Z = -2.18, p = .03; Picture: Z = -2.67, p = .01). Paired testing (Wilcoxon) within each of the three groups revealed no differences in the number of errors made on the verbal and non-verbal tasks.

The impact of aphasia and neglect: left hemisphere patients with and without aphasia

Decision times. The analysis (ANOVA) of the differences between left hemisphere patients with and without aphasia revealed that the aphasic patients were significantly slower on the Text task (F = 8.92, p = .01). There were no differences between the left hemisphere patients without aphasia and the control subjects on either task.

Error rates. The error rates of left hemisphere patients with and without aphasia are presented in Table 4. The error rates of patients with and without aphasia did not differ significantly (Text Z = -1.80, p = .07; Picture Z = -1.82, p = .07). When the aphasic patients were excluded however, the differences between left hemisphere patients and the control group were no longer significant (Text Z = -1.15, p = .25; Picture Z = -1.52, p = .13).

The impact of aphasia and neglect: right hemisphere patients with and without neglect

Decision times. The decision times of right hemisphere patients with and without neglect were compared using ANOVA. Neglect patients were significantly
slower than patients without neglect on nearly every task (RT1-ipsi F= 9.75, p< .01; RT1-contra F= 11.29, p< .01; RT8-ipsi F= 1.32, p=.26; RT8-contra F= 12.59, p< .01; Text F= 9.64, p< .01; Picture F=12.03, p< .01). Right hemisphere patients without neglect were significantly slower than the control group on both visuomotor tasks (RT1-ipsi F= 6.91, p= .01; RT1-contra F= 11.61, p< .01; RT8-ipsi F= 11.01, p< .01; RT8-contra F= 18.18, p <.01), but not on the cognitive tasks.

**Error rates.** The Mann Whitney test showed no significant differences between the error rates of right hemisphere patients with and without neglect. The error rates are presented in table 4.

**The impact of aphasia and neglect: aphasia and neglect as predictors of decision time**

To examine the relative contribution of neglect and aphasia to the task performance of right and left hemisphere patients more closely, we conducted stepwise regression analyses. In table 5 the significant predictors are presented. Within the right hemisphere group neglect was an important predictor for the visuomotor decision times. This is especially true for the decision times for the stimuli presented in the visual field contralateral to the side of the lesion. Twenty-five percent of the variance in decision time was explained by the presence of neglect. Neglect and aphasia together predicted 35% of the variance in the Text task and 33% of the variance in the Picture task. In the left hemisphere group, aphasia explained 17% of the variance in the decision times on the Text task. Neither aphasia nor neglect contributed to the other reaction times within the left hemisphere group.

Table 5:  *Contribution of aphasia and neglect to the decision times.*

<table>
<thead>
<tr>
<th>Lesion side</th>
<th>Decision time</th>
<th>Predictor</th>
<th>R²</th>
<th>Significance (p=&lt;.01)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Right</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>RT1$&amp;$RT8 ipsi</td>
<td>neglect</td>
<td>.15</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>RT1$&amp;$RT8 contra</td>
<td>neglect</td>
<td>.25</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>Text</td>
<td>neglect</td>
<td>.19</td>
<td>***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>aphasia</td>
<td>.22</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>neglect $&amp;$ aphasia</td>
<td>.35</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Picture</td>
<td>neglect</td>
<td>.24</td>
<td>***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>aphasia</td>
<td>.16</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>neglect $&amp;$ aphasia</td>
<td>.33</td>
<td></td>
</tr>
<tr>
<td><strong>Left</strong></td>
<td>Text</td>
<td>aphasia</td>
<td>.17</td>
<td>*</td>
</tr>
</tbody>
</table>
Conclusions & discussion

The analysis of the healthy subjects showed that the more complex the information to be processed, the longer the processing time. This is not exactly a new finding. Over 100 years ago, Donders (1818-1889) found similar results on reaction time task measures of decision processes (Eling & Brouwer, 1995). One of the main questions in this study was whether task difficulty is also expressed in decision time in unilateral stroke patients.

Analyses of the performance of the healthy subjects showed that our reaction time battery has three different levels of complexity. Within the visuomotor tasks the RT8 is more complex than the RT1, within the categorisation tasks the Picture-task is more complex than the Text-task, and finally the categorisation tasks overall are, as expected, more difficult than visuomotor tasks. Unexpectedly, task difficulty had a significant effect not only on decision times, but also on movement times. Factor analyses, however, showed that the decision times and the movement times clearly reflect different aspects of responding. These can be interpreted as: ‘visuomotor decision time’, ‘cognitive decision time’ and ‘movement time’. In line with expectations, interactions between group and difficulty were found in the decision times, but not in the movement times. Movement times in the patient groups were longer than in the control group only for the cognitive tasks. These differences are most likely due to a decision component in the movement time. Many subjects were apparently still thinking about the right answer while they were moving their hand towards the response buttons.

In contrast to the results of Dee and van Allen (1973), our results suggest that, in the right hemisphere group, there might be a complexity effect within the visuomotor tasks. The analyses reveal that right hemisphere patients are slower than both left hemisphere patients and the control group on the visuomotor tasks, and that this effect is more pronounced in the RT8 than the RT1. There are, however, several other factors that could be responsible for this seeming complexity effect in the right hemisphere patients.

First of all, the decision times of the right hemisphere group are prolonged in the RT8 when the stimuli are presented in the contralateral, but not the ipsilateral, visual field (see figure 3). This might indicate that the right hemisphere patients have an attentional bias towards the right sided stimuli in the RT8. This is congruent with the theory that the right hemisphere monitors the distribution of attention in, and shifts attention to, both sides of the visual field, while the attentional capacities of the left hemisphere are mainly restricted to the contralateral visual field. According to this model right hemisphere lesions can lead to severe contralesional neglect because the left hemisphere cannot compensate for the difficulty in shifting attention to the left hemispace. Deficits in spatial attention after left hemisphere damage are less likely, because they can be compensated for by the capacities of the right side of the brain (Mesulam, 2000).
A second reason to doubt the presence of a complexity effect in the right hemisphere patients is the fact that they are not disproportionately bothered by the complexity of the most difficult tasks, the cognitive tasks. They are slower than the control subjects, but the increased complexity does not lead to a disproportional increase in decision time. Finally, the question arises whether the RT8 should really be interpreted as a task with eight choices. In our eight choice task there is only one type of stimulus, a stimulus light, and one type of response, pressing the stimulus light. In the choice tasks used by Dee & Van Allen (1973) and Tartaglione and co-workers (1991) the subjects had to press the response button with the same colour as the stimulus light. This means that after perceiving the colour of the stimulus light, they had to select the correct response button. In our RT8, the stimulus light is the response button. It differs from RT1 mainly in the fact that the stimulus location varies randomly during the test. The RT8 is therefore likely to place higher demands than the RT1 on spatial attentional capacity but not on the decision making process. This is supported by the fact that in the Dee & van Allen (1973) and Tartaglione (1991) experiments, subjects made errors, while no errors were made in our visuomotor tasks. Apparently right hemisphere stroke patients are slower than age-peers when attention has to be divided over both visual half fields; they show an attentional bias towards the ipsilesional stimuli. They are not especially bothered, however, when an increased demand is made on their higher order cognitive processing capacities, as measured with the categorisation tasks. To this extent our findings are in line with those of Dee and van Allen (1973).

The decision times in the left hemisphere patients showed a completely different pattern. These patients were not slower on the visuomotor tasks than the control group. Egelko and colleagues (1989) also found left hemisphere patients to perform normally on a simple reaction time task. Other studies, however, have found left hemisphere patients of various aetiologies to be slower than control subjects on simple reaction time tasks (Kaizer, et al., 1988; Dee & Van Allen, 1971; Howes & Boller, 1975). In an overview Benton (1986) emphasised that while left hemisphere patients are slower than control subjects in some studies and not in others, they are never slower than right hemisphere patients on simple reaction time tasks.

When we compared the decision times on the visuomotor tasks and the higher order cognitive tasks, the left hemisphere patients were disproportionately bothered by the increased complexity. However, this interaction was caused by the fact that the decision times of left hemisphere patients were unimpaired on the visuomotor tasks, not by their being significantly slower than the right hemisphere patients on the categorisation tasks. The left hemisphere patients were not slower than the right hemisphere patients on any task. The cognitive complex reaction time tasks appeared to be the only tasks on which their decisions were slowed compared to the control group. Moreover they made more mistakes than the control group did, whereas the right hemisphere patients did not differ from the control group. This is congruent with the finding of Tartaglione and colleagues.
that the impairment in the decision making process in left hemisphere patients compared to right hemisphere patients was expressed in the accuracy but not in the latency of the responses.

To examine the influence of language disorders, we repeated the analysis of the error rates and decision times without the aphasic patients. The differences between left hemisphere patients and control subjects in number of errors disappeared. The presence of aphasia explained 17% of the variance in the decision times on the Text-task. Aphasia did not seem to have any significant influence on the other tasks. When the left hemisphere patients with and without aphasia were compared, the aphasics performed more poorly than the non-aphasic patients on the Text-task only. Yet, when the aphasic patients were excluded, the left hemisphere patients appeared to have normal decision times on all the reaction time tasks. Still, considering the fact that aphasia explained only 17% of the variance in the Text-task and made no significant contribution to the Picture-task, it is unlikely that the slowness in left hemisphere patients was caused only by language problems. In our group of 46 left hemisphere patients, one third was classified as having some degree of language difficulty. Excluding patients with language problems meant excluding a substantial number of patients, probably including those with the most severe damage.

In our study neglect was an important predictor of the decision times for stimuli in the contralateral visual field; 25% of the variance in the reactions to contralateral stimuli was explained by neglect. It is therefore not surprising that decision times on all the reaction time tasks, except for the right-sided RT8 stimuli, were significantly longer in right hemisphere patients with neglect. When the neglect patients are excluded from the analyses, the right hemisphere patients remain slower than the control group on both visuomotor reaction time tasks.

In conclusion, these results show that stroke may cause a decrease in mental speed, but they are not as convincing as the data showing slowness of information processing after traumatic brain injury (Spikman, van Zomeren, & Deelman, 1996; van Zomeren, 1981; Ponsford & Kinsella, 1992). Subjectively, mental slowness is a major cognitive complaint in both traumatic and stroke patients (Hochstenbach, 1999; Spikman, et al., 1996; Visser-Keizer, Meyboom-de Jong, Deelman, Berg, & Gerritsen, 2002). Objectively, there seems to be a basic mental slowness in the right hemisphere stroke patients, which affects all the reaction time tasks, but is not sensitive to the addition of a higher order cognitive component to the test. It is sensitive however, to the visual field in which the stimuli are presented. Decisions about contralesional stimuli are slower than decisions about ipsilesional stimuli. The left hemisphere patients, however, did not show a basic slowness at all, not even when the visuomotor task became quantitatively more complex. Only when the task became cognitively more demanding did decision time increase significantly compared to the control group. In contrast to our expectations, the complexity effect, as defined by van Zomeren & Deelman (1976) and Miller (1970), could not explain our results.
References


