Objectives: To identify the extent of cognitive motor interference (CMI) in sitting balance during recovery from stroke; to compare CMI in sitting balance between stroke and non-stroke groups; and to document any changes to CMI during sitting that correlate with functional recovery.

Method: Thirty-six patients from stroke rehabilitation settings in three NHS Trusts. Two healthy control groups: 21 older 21 young volunteers. Measures of seated postural sway were taken in unsupported sitting positions, either alone or concurrently with repetitive speech output, or oral word category generation. Outcome measures were variability and path length of sway and number of valid words generated.

Results: Stroke patients were less stable than controls during all unsupported sitting tasks, they demonstrated greater sway during repetitive speech compared to quiet sitting, but did not show postural discrimination between repetitive speech and word category generation. CMI for the stroke group was not markedly different to control participants but sway during repetitive speech was highly negatively correlated with functional recovery on the Barthel ADL index.

Conclusions: Spoken output during unsupported sitting balance has potential clinical relevance for forecasting the rate of functional recovery.

Despite advances in preventative care and health promotion, stroke still represents a major source of disability among older adults [1]. Symptoms often include disruption of postural and movement control and cognitive processing. Either or both of these may adversely affect the ability to participate in therapy, perform activities of daily living and live independently. There is now a substantial body of evidence that a thorough multidisciplinary assessment of the patient early after stroke, followed by a dedicated programme of active care leads to reduction in disability [2] [3]. However, the extent to which motor and cognitive components of functional ability may impact on one another during recovery from stroke and affect responsiveness to rehabilitation are only beginning to be understood. To give a simple example, therapy aimed at restoring motor function is unlikely to be effective if the patient lacks the cognitive capacities such as attention and memory required to encode instructions during therapy.

Motor control is traditionally assumed to be largely automatic in normal, healthy adults [4]. However, investigations of variations in motor activity in combination with tasks that place different demands on cognitive resources, suggest that motor control and cognitive function do not proceed entirely independently. Rather, a concurrent cognitive task may have measurable effects on motor output patterns and vice versa. The extent to which cognitive and motor control mutually disrupt each other has been shown to vary according to sensory context [5], cognitive demands of concomitant task [6], type of cognitive processing required [7], expertise of the participant [8], or their level of executive function [9].

In dual-task methodology, performance on motor and/or cognitively demanding tasks is carried out simultaneously. The performance measures in the dual-task condition are compared with those in conditions where each task is carried out singly. The dual-task method therefore allows cognitive-motor interference (CMI) to be quantified. CMI has been shown to be a sensitive means of investigating
competing demands on processing resources [10]. As such, the investigation of CMI may play an even greater role in recovery from neurological damage, such as stroke. During recovery, motor co-ordination patterns may have to be re-learnt and so become, at least temporarily, more attention-demanding. However, much less research has been published in this area than in normal ageing. Studies of gait control have indicated that listening and responding to a simple sustained auditory attention task can slow walking [11] and that some patients demonstrate a significant dual-task decrement in both stride duration and cognitive output [10]. Recently Hyndman and Ashburn [12] have noted that over 40% of a community-based sample of older stroke patients stopped walking when a conversation was initiated.

Each of the three studies cited above has used gait as the motor component and spoken output for cognitive tasks but Yardley and colleagues [13] [14] have suggested, on the basis of evidence from healthy young adults as well as patients with vestibular disease that the mechanisms for spoken output do impact on measures of postural control. Therefore, when using verbal tasks during static balance it is important to consider the effect of thoracic movements on stability as these may otherwise lead to exaggerated estimates of cognitive interference on motor control. This study includes both cognitively demanding and undemanding speech conditions to examine their respective contributions to balance instability.

Reacquisition of sitting balance is recognised as an important early milestone in functional recovery after stroke [15], and was therefore the focus of our study. However, the changes in attentional demands of cognitive and motor processes during the course of recovery, and the impact of these changes on functional ability, are yet to be systematically explored. The aims of the study were to identify the extent of CMI in a sample of people who were beginning to reacquire independent sitting balance in the early stages of stroke recovery; to compare the effects of dual tasks on sitting balance between stroke patients and healthy controls; and to document the value of any changes to sitting balance during divided attention that correlate with clinical measures of functional recovery.

METHODS
Participants
Thirty six stroke patients (23 male, mean age 61.58 (SD 15.88) years) were recruited from in-patient stroke rehabilitation settings in three NHS trusts in the south of England. They were invited to take part in the study if, in the opinion of their treating physiotherapist, they still showed some instability in sitting balance but would be able to sit unsupported for periods of at least one minute at a time and be able to complete four consecutive one-minute trials. The study met the criteria of the local Research Ethics committees and all participants, where possible, gave written informed consent. Those unable to write nominated a family member or member of nursing staff to sign for consent. Individuals were excluded from the study if they were unable to give consent or had insufficient comprehension or expressive speech to perform the cognitive tasks. Basic demographic information for stroke patients is summarised in Table 1.

Two additional groups of participants with no history of neurological illness were recruited as controls. There were 21 in the older group (mean age 71.05 (SD 7.49) years) recruited from the Volunteer Ageing panel of the School of Psychology, University of Reading, and a further 21 in the young group (mean age 20.62 (SD 3.71) years), all of whom were psychology undergraduate students. Participants in the
older group were reimbursed travel expenses and students participated for course credit.

**Materials**

Unsupported sitting balance was measured via a modified Balance Performance Monitor™ (BPM) seat (dimensions 49.5 cm x 30 cm x 2.5 cm), which had four force sensors, one in each corner. The BPM was placed on a customised supporting seat on an adjustable plinth so that all participants were able to sit with their feet comfortably reaching the floor, with knees and hips at 90 degrees. Data were recorded as separate voltage outputs from each of the four transducers through a data acquisition card in a laptop computer. Each trial was one minute in duration.

Cognitive performance was measured by a word category generation task, similar to the measure used by Haggard et al [10]. Participants were given four target category names, e.g. boys’ names, and asked to supply exemplars from each category for one minute. Two categories were used in single-task (sitting supported) and two in dual-task (sitting unsupported) conditions. Order of presentation was systematically varied across participants. Responses were recorded via a head mounted microphone.

A second oral condition was included to assess whether speech output could influence postural control in the absence of any cognitively demanding, ‘effortful’, spoken output. In this task, participants were asked to repeat the sound ‘ba’ for approximately 8 seconds at a rate of one per second. They were then given a signal to stop for 8 seconds. This cycle was repeated, giving four on/off periods over one minute. This task was recorded for analysis only as a dual-task during unsupported sitting. Instructions were given as for category generation.

Other measures taken for the patient group were: Short Orientation Memory Concentration test (SOMC) [16], to assess awareness and basic cognitive functioning; The Star Cancellation test [17] [18] to assess for visuospatial neglect; and the Physical and Mental subscales of the Fatigue Impact Scale [19], all at time of assessment. Score on a version of the Barthel ADL Index [20] was also recorded at the time of assessment and one and three months later. All controls had at least average IQ, based on National Adult Reading Test [21] score. In addition all older adults had an MMSE [22] score of at least 24 / 30.

**Procedure**

Participants were tested in a quiet room at the hospital or centre they were attending. Sitting balance was recorded in three unsupported conditions. During these trials participants were required to sit upright and maintain as still a posture as possible while carrying out the tasks: sitting still only (US); saying ‘Ba’ repeatedly (UB); and category word generation (UW). For supported word generation trials (SW), the participants rested back into the supporting seat and generated words. During each unsupported trial, the back support was removed and the participants had to hold themselves upright. Throughout the unsupported trials the research physiotherapist stood behind the patients ready to intervene and provide support if the patient began to tilt alarmingly over the course of the one-minute trial. Support was returned between trials for the participants to rest. Trials in which physiotherapist support was required were removed from the data and were repeated where possible. Word category generation was tested in supported (SW) and unsupported sitting (UW). Single task trials were US and SW and the dual task trials were UW and UB. The four trials were each repeated two times in separate testing blocks, arranged in a sandwich design to minimise the effects of practice and fatigue.
RESULTS

Patient demographic data

The patients varied considerably in both age and time since stroke (Table 1). This pattern is not untypical in stroke rehabilitation. There was a significant negative correlation between days post onset and SOMC ($r = -0.383$, $p<0.05$) such that patients with more recent stroke had lower SOMC scores. In addition, patients with higher SOMC scores correlated with higher word generation scores during supported ($r = 0.448$, $p<0.05$) and unsupported ($r = 0.518$, $p<0.01$) sitting. Ten of the 33 patients who did the Star Cancellation test scored below the cut-off point of 51, indicating possible visuo-spatial neglect, and there was a significant correlation between Star Cancellation and Barthel ADL Index score ($r = 0.451$, $p<0.01$) but no significant correlation between Star Cancellation score and any of the experimental measures. Patients with left hemisphere stroke were only included in this study if they had adequate comprehension and expressive language ability to give informed consent and to perform the word fluency task. The side affected by stroke and Scores on the Fatigue Impact Scale were not related to differences between patients or any clinical or experimental measure.

Table 1 Descriptive Statistics: Patient group.

<table>
<thead>
<tr>
<th>Task</th>
<th>N</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>36</td>
<td>23</td>
<td>91</td>
<td>61.58</td>
<td>15.88</td>
</tr>
<tr>
<td>Days Post</td>
<td>36</td>
<td>22</td>
<td>214</td>
<td>68.86</td>
<td>49.74</td>
</tr>
<tr>
<td>Barthel (at testing)</td>
<td>36</td>
<td>6</td>
<td>20</td>
<td>12.86</td>
<td>3.68</td>
</tr>
<tr>
<td>SOMC</td>
<td>34</td>
<td>7</td>
<td>28</td>
<td>22.12</td>
<td>5.76</td>
</tr>
<tr>
<td>Fatigue</td>
<td>36</td>
<td>0</td>
<td>70</td>
<td>26.94</td>
<td>14.25</td>
</tr>
<tr>
<td>Star Cancellation</td>
<td>33</td>
<td>7</td>
<td>56</td>
<td>47.33</td>
<td>14.49</td>
</tr>
<tr>
<td>Right hemisphere stroke</td>
<td>25</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left hemisphere stroke</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Postural orientation

Centre of pressure was measured for each trial to detect any bias for leaning forwards, backwards, or to one side. Results indicated that most participants sat a little forward on the seat, the young group tended to position themselves slightly to the right of centre, and the older and stroke groups sat left of centre. All participants adjusted their posture forwards for the unsupported conditions, but the mediolateral position was unaffected by the cognitive or sitting tasks. During unsupported quiet sitting (US), the young group were quite stable and moved only a short distance in the anteroposterior and mediolateral axes (mean 1.43 cm (SD 0.54)). The older and the stroke groups both swayed across a larger area than the young group (older mean 2.46 cm (SD 0.99), stroke mean 2.61 cm (SD 1.51)). The difference between the older and stroke groups was small but the variability within the stroke group for this measure was large.

Postural control

Sitting balance was assessed using two measures: variability of sway, and total additive movement (path length), for the 60-second duration of each trial. A series of repeated measures analyses of variance (ANOVAs) were performed to examine
differences across groups in the balance measures as participants carried out the unsupported sitting tasks (US, UB, and UW) for each testing block (block 1, block 2). The stroke group showed the greatest variability of position, $F(2, 75) = 6.62, p<0.001$; they were significantly more variable than the young controls ($p<0.001$) but the difference with the older controls was not significant. The variability of sway was influenced by task demands, but the effect of the tasks on posture was different between the stroke and the control groups, $F(4, 150) = 4.87, p<0.01$. For the stroke patients, both variability of sway on the mediolateral and anteroposterior axes, increased during UW compared to US ($p<0.01$). The same result was found for the control groups but sway variability during UW was found to be greater than during UB ($p<0.01$). There was an effect of fatigue for all participants, that was evident as increased variability on both axes from block 1 to block 2 during US and UW trials, $F(1, 75) = 20.92, p<0.001$.

**Figure 1** Variability of sway from starting position for each group during still sitting (US), repetitive speech (UB), and for unsupported word generation (UW).

Path length for the stroke group was significantly greater than for the control groups, $F(2, 75) = 24.05, p<0.001$; and the difference between the control groups was not significant. The effect of the unsupported tasks on path length was different across the groups, $F(4, 150) = 4.15, p<0.05$. For the stroke group path length was longer during UW compared to US ($p<0.001$) and was also longer during UB compared to US ($p<0.001$) but there were no differences between UB and UW. For the older controls, path length increased during UW compared to US ($p<0.01$) but there were no differences between UB and US. The older controls also showed increased path length during UW compared to UB ($p<0.01$). The young control group showed no significant differences in sway path between the three tasks. There were no significant differences in path length between blocks 1 and 2 for any participants.
Word category generation
Repeated measures ANOVA examined the effect of sitting support (supported, unsupported) and testing block (block 1, block 2) on number of words generated across groups. All participants generated more words during supported compared to unsupported sitting, F(1, 69) = 28.85, p<0.001; but there were no differences between block 1 and block 2. More words were generated by the control groups than the stroke group, F(2, 69) = 20.74, p<0.001, but there were no differences between the control groups.

Table 2 Mean scores for word category generation during supported and unsupported sitting.

<table>
<thead>
<tr>
<th></th>
<th>Supported Sitting</th>
<th>Unsupported Sitting</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Young</td>
<td>25.17</td>
<td>4.57</td>
</tr>
<tr>
<td>Elderly</td>
<td>26.36</td>
<td>7.02</td>
</tr>
<tr>
<td>Stroke</td>
<td>14.81</td>
<td>7.39</td>
</tr>
</tbody>
</table>

Proportional dual task costs
The cognitive motor interference (CMI) for both sway variability and path length was calculated, as the percent change in sitting stability for the unsupported word tasks from the unsupported no word task. This calculation revealed that for sway variability, the attentional cost (CMI) for UW was greater than for UB, F(1, 75) = 51.14, p<0.001 for all participants. There were no group differences for CMI during the UB task, but the older adults demonstrated greater CMI than both the stroke group (p<.05) and the young group (p<.05) during UW. The effect of CMI on path length
was greater during UW than UB, F(1, 75) = 11.26, p<.001. The stroke group experienced greater CMI during UB compared to both the older (p<.05) and the young (p<.01) control groups. CMI during UW was greater for the stroke group compared to the young only (p<.001), there were no significant differences between the stroke and older groups, but the older group experienced greater CMI than the young (p<.001). There was no evidence of increased CMI between block 1 and block 2. The dual task cost of generating words whilst sitting unsupported was also calculated. There were no differences between the groups and no differences between the testing blocks.

Figure 3 Percent change in variability of movement during unsupported repetitive speech and unsupported word category generation compared to unsupported still sitting. Measures are presented for each group.

Figure 4 Percent change in total movement measured as path length during unsupported repetitive speech and unsupported word category generation compared to unsupported still sitting. Measures are presented for each group.
For the stroke patients, the measures of sitting balance (US, UB, and UW) significantly correlated with the clinical scores of the Barthel ADL at various times during and after testing. The correlations between the postural measures and Barthel are listed in Table 2. Variability and path length did not correlate with word generation performance, in either supported or unsupported sitting conditions.

**Table 3** Correlation between Barthel ADL scores and sitting balance measures at time of testing, 1 and 3 months post testing.

<table>
<thead>
<tr>
<th></th>
<th>Variability</th>
<th>Path Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>US  UB  UW</td>
<td>US  UB  UW</td>
</tr>
<tr>
<td>Barthel 0</td>
<td>36 - .328 - .409 * - .095</td>
<td>- .044 .004 .093</td>
</tr>
<tr>
<td>Barthel 1</td>
<td>36 - .069 - .367 * - .300</td>
<td>- .100 - .226 -.110</td>
</tr>
<tr>
<td>Barthel 3</td>
<td>36 - .261 - .430 ** - .420 *</td>
<td>- .135 - .201 -.117</td>
</tr>
</tbody>
</table>

* Indicates correlation is significant at the 0.05 level (2-tailed).
** Indicates correlation is significant at the 0.01 level (2-tailed).

**DISCUSSION**

Balance during unsupported quiet sitting was more variable and unstable for the stroke patients than for the healthy controls. Postural instability during unsupported sitting was shown to increase significantly when patients carried out the repetitive speech task compared to sitting still but did not increase further when generating words. In contrast controls showed no marked disruption to sitting balance during repetitive speech but the older controls did show greater instability during word generation, which was not related to measured cognitive skills.

These results suggest that speech output has a major disruptive influence on posture control following stroke, independent of the content of what is spoken. A task requiring thinking plus spoken output did not produce any additional decrement, but the rate of word generation was significantly less amongst stroke patients than controls. This may account for the lack of an additional effect, but we assume that the stroke patients were applying as much cognitive effort into producing the lower number of words as controls were for their higher output. It is possible that the thoracic movements involved in speech output directly disrupt balance in the stroke patients [13], but there was no evidence to indicate that sway increased proportionally with the number of speech outputs made. For this reason, the results are more suggestive of a model of attentional interference: that any task carried out during unsupported sitting will result in competition for limited attention resources and will result in postural interference [10]. Although the repetitive speech task imposes less cognitive load than word generation it nevertheless requires attention to maintain an output stream.

There were significant negative correlations between the measures of sitting balance variability and the Barthel ADL scores, demonstrating that the patients with higher Barthel scores in this study had less variable sitting balance than the patients with lower Barthel scores. This correlation was still evident at one and three months post testing, with variability during repetitive speech being most strongly correlated with Barthel, although variability during word generation also correlated significantly with Barthel scores at three months. The relationship between the variance of sitting
stability during repetitive speech and the Barthel index could be useful alongside clinical measures for assessing and predicting both cognitive and functional recovery from stroke. It is possible that patients whose balance is unaffected by repetitive speech may recover functional independence faster than those for whom there is significant instability during this task compared to still sitting. The long-term predictive validity of these measures needs to be assessed and a wider range of cognitive tasks used to determine whether there are more subtle changes to cognitive and motor recovery following stroke.

Fatigue is a significant problem for stroke patients [23], especially during the early stages of recovery and can be detrimental to the amount of time spent engaged in activities. In this study a number of patients were unable to complete the two blocks of tasks in one session, and all patients showed signs of fatigue with greater variability in sitting position during block 2 compared to block 1. We were surprised to find that the healthy adults were also less stable in block 2 and were showing signs of fatigue. Unsupported sitting is a challenging task for stroke patients and healthy active controls alike. It has been a suitable tool for determining functional recovery following stroke and can be used to discriminate postural control in healthy participants for investigations into the dual task interference between cognitive and motor activities [24]. Self-reported fatigue state, as measured by the Fatigue Impact Scale did not reflect the task-associated fatigue observed in the patients between blocks 1 and 2 of this study. Measures of unsupported sitting could be of use as an objective measure of physical fatigue during stroke recovery.

The present study has made a strong contribution to understanding the influence of dual tasks on sitting postural control. It suggests that it is not just general cognitive effort that may produce interference, but a speech task that has a high output rate, with low cognitive load, may produce equivalent impact. Further investigations to systematically assess the relative influence of cognitive and non-cognitive speech tasks, and non-verbal cognitive tasks, on sitting stability, would be valuable to fully understand the conflict between attention and postural control following stroke.

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