Validity of a Virtual Environment for Stroke Rehabilitation

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Background and Purpose—Virtual environments for use in stroke rehabilitation are in development, but there has been little evaluation of their suitability for this purpose. We evaluated a virtual environment developed for the rehabilitation of the task of making a hot drink.

Methods—Fifty stroke patients undergoing rehabilitation in a UK hospital stroke unit were involved. The performance of stroke rehabilitation patients when making a hot drink had the neurological impairments associated with performance of this task, and the errors observed were compared for standardized task performance in the real world and in a virtual environment. Neurological impairments were measured using standardized assessments. Errors in task performance were assessed rating video recordings and classified into error types.

Results—Real-world and virtual environment performance scores were not strongly associated ($r=0.30; P<0.05$). Performance scores in both settings were associated with age, Barthel ADL score, Mini Mental State Examination score, and tests of visuospatial function. Real-world performance only was associated with arm function and sequencing ability. Virtual environment performance only was associated with language function and praxis. Participants made different errors during task performance in the real world and in the virtual environment.

Conclusions—Although this virtual environment was usable by stroke rehabilitation patients, it posed a different rehabilitation challenge from the task it was intended to simulate, and so it might not be as effective as intended as a rehabilitation tool. Other virtual environments for stroke rehabilitation in development require similar evaluation.

Key Words: cerebrovascular disease • rehabilitation • virtual reality

There is increasing research interest in the application of virtual reality technology in psychotherapy,1 motor rehabilitation,2 and rehabilitation of people with intellectual disabilities.3 Virtual environments have been used to support learning of activities of daily living, including kitchen skills,4,5 road crossing,6,7 catching a bus,8 shopping,9,10 and social interaction.11

Virtual environments are potentially useful in stroke rehabilitation because they might be safer than attempting hazardous tasks in the real world.12 They may also have educational benefits; compared with the real world, virtual environments can enable earlier rehabilitation because they can be simpler, feedback can be more consistent or enhanced, and some people find interaction with them enjoyable and compelling. Virtual environments have the potential to enhance aspects of modern neuro-rehabilitation techniques; virtual environments can potentially be more precisely controlled than many real-world settings, intensive practice and repetition of tasks can be easier, and progress can be recorded automatically.

The very people who might require rehabilitation, such as elderly stroke patients with multiple impairments, may find it difficult to interact with, and benefit from, virtual environments. However, demonstration projects show that virtual reality systems are acceptable to patients with stroke and traumatic brain injury.13–18 They have been evaluated as assessment and therapeutic tools for cognitive ability or motor skills,19 but there been only a few controlled studies.17,20

Even if patients with stroke can use such systems, little is known about whether the neurological impairments that affect the performance of a task in a virtual environment are similar to those that affect real-world task performance, whether mistakes made by patients in virtual and real world are similar, and, hence, whether a virtual environment is a suitable training environment. For example, visual neglect is a common cause of problems in real-world functional tasks after stroke and it is known that neglect can appear or disappear depending on the exact cognitive requirements.21 Therefore, it needs to be established whether neglect would appear in virtual environment so that training in that environ-
ment might have carry-over effects into the real world. Similar questions can be raised about other impairments seen after stroke.

Making a hot drink is commonly retrained during rehabilitation, normally requires repeated training in a real kitchen, involves significant therapist time, and safety concerns prevent unsupervised practice. In the UK, many patients have limited training in hospital and go home unable to perform this basic task. On the basis that it was a useful application of virtual environment training, we have developed a virtual hot drink-making task.

We investigated if stroke patients in rehabilitation were able to interact with this virtual environment and assessed its validity by testing the following 3 hypotheses: (1) there is a correspondence between ability to make a hot drink in the real world and in the virtual environment; (2) the impairments affecting virtual and real-world task performance are similar; and (3) stroke rehabilitation patients make similar errors when performing virtual and real-world tasks.

**Materials and Methods**

Participants were recruited from the Stroke Unit, Queens Medical Centre, Nottingham, UK. Patients were suitable if they had a diagnosis of stroke, were medically stable, undergoing rehabilitation, and had a goal of returning home. Patients with dementia, major psychiatric illness, epilepsy triggered by screen images, those unable to speak English or hear ordinary speech, with no upper limb function, and those enrolled in other studies were excluded.

After written consent, demographic and basic stroke-related data were collected, and participants were assessed using standardized measures of cognitive and motor function, hot drink-making performance in the real world and in the virtual hot drink-making environment. The assessments were performed over >1 session and in the aforementioned order. The standardized assessments of cognitive and motor function used were:

- **Language:** Sheffield Aphasia Screening Test
- **Global cognition:** Mini-Mental State Examination
- **Visual attention:** Star Cancellation
- **Visuospatial function and memory:** Rey Figure Copying and Recall
- **Verbal memory:** Story Recall from Rivermead Behavioral Memory Test (RBMT)
- **Visuospatial function:** Object Decision and Number Location subtests from Visual Object and Space Perception Battery (VOSP)
- **Sequencing:** Sequencing Pictures from Rivermead Perceptual Assessment Battery (RPAB)
- **Attention:** Tone Counting subtest from Test of Everyday Attention (TEA)
- **Praxis:** Kimura Box
- **Arm function:** 10-Hole Peg Test
- **Motor function:** Motricity Index
- **Functional ability:** Barthel ADL Index

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Functional ability: Barthel ADL Index

Hot drink-making in the real world was assessed as follows. Participants were video-recorded making a hot drink in a rehabilitation kitchen according to a standardized protocol, using either or both upper limbs, and under supervision by an occupational therapist. The assessment schedule included 27 possible subtasks, of which 12 subtasks were compulsory and 15 subtasks were optional. There was no set order in which the subtasks had to be completed except for logistical or safety reasons (e.g., water must be in the kettle

**TABLE 1. Recruitment of Participants**

<table>
<thead>
<tr>
<th>Reason not Recruited</th>
<th>N (%)</th>
<th>n=167</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not suitable for rehabilitation</td>
<td>50 (30)</td>
<td></td>
</tr>
<tr>
<td>Rehabilitation complete: awaiting discharge</td>
<td>-12</td>
<td></td>
</tr>
<tr>
<td>Medically unwell</td>
<td>-5</td>
<td></td>
</tr>
<tr>
<td>No goal of returning home</td>
<td>-33</td>
<td></td>
</tr>
<tr>
<td>Not suitable for virtual rehabilitation</td>
<td>42 (25)</td>
<td></td>
</tr>
<tr>
<td>Dementia or psychiatric illness</td>
<td>-17</td>
<td></td>
</tr>
<tr>
<td>Screen triggered epilepsy</td>
<td>-1</td>
<td></td>
</tr>
<tr>
<td>Prestroke deafness</td>
<td>-1</td>
<td></td>
</tr>
<tr>
<td>Not able to speak English before stroke</td>
<td>-7</td>
<td></td>
</tr>
<tr>
<td>Poor visual acuity</td>
<td>-6</td>
<td></td>
</tr>
<tr>
<td>No upper limb function</td>
<td>-2</td>
<td></td>
</tr>
<tr>
<td>Poor communication (insufficient to give consent)</td>
<td>-8</td>
<td></td>
</tr>
<tr>
<td>Enrolled in other studies</td>
<td>2 (1)</td>
<td></td>
</tr>
<tr>
<td>Declined to give consent</td>
<td>23 (14)</td>
<td></td>
</tr>
<tr>
<td>Recruited</td>
<td>50 (30)</td>
<td></td>
</tr>
</tbody>
</table>

Figure 1. Virtual environment display.
before the electricity is switched on). Videos were scored by trained assessors. Each subtask was scored according to the level of independence (ie, independent, required verbal assistance, or dependent/required physical assistance). A total score was calculated, being the ratio of the sum total of subtasks completed compared with the number of subtasks that were attempted, and expressed as a percentage.

The virtual environment was displayed and interacted with using a laptop computer touch screen and handheld stylus. The required components (eg, kettle, instant coffee) were displayed on the screen (Figure 1). Participants had to tap the required object with the stylus to select it and a second tap was required at the object’s destination to trigger its animation. Immediate feedback was provided by an auditory message saying whether each subtask had been performed correctly. If the participant did not continue with the next subtask within 20 seconds, there was an auditory prompt asking, “What would you do now?” If the participant was unable to initiate the next subtask, there was an auditory instruction of the next subtask (eg, “pour the boiled water from the kettle into the teapot”) and if the participant remained unable to complete the subtask, the system demonstrated the subtask on screen. Additional cues provided by the system included a “ping” sound and an arrow above an object when it was selected. Participants were taught how to operate the touch screen interface in a practice virtual task involving putting a letter in an envelope. A virtual hot drink-making score was calculated as in the real-world assessment.

Errors during task performance were assessed as follows. Participants were video-recorded during real world and virtual environment task performance. The video tapes were subsequently viewed to classify error types in task performance using a schedule based on published literature and clinical experience comprising problems with initiation, attention, neglect, addition, sequence omission, perseveration, selection, object use, problem solving, dexterity, quantity, and spatial awareness. Error analysis was undertaken on a sample of the paired video recordings of 20 participants.

### Results

Fifty participants were recruited between March 2004 and May 2005 from the 167 stroke patients identified (Table 1). The mean age of the participants was 69 years, 26 were men, 21 had a right and 29 had a left hemiparesis, 37 had anterior circulation, 10 had lacunar strokes, and 3 had posterior circulation strokes. Participants demonstrated a typical range of stroke-related impairments (Table 2).

During the real-world task, 39 participants mainly used their dominant hand (which was the paretic side in 29 of these) and 11 relied on the nondominant hand. During interaction with the virtual environment, 40 participants

![Figure 2. Real and virtual world assessment percentage scores.](http://stroke.ahajournals.org/DownloadedFrom)
TABLE 3. Correlations Between Clinical Variables and Standardized Tests With Degree of Independence on Real-World and Virtual Hot Drink-Making Performance

<table>
<thead>
<tr>
<th>Test</th>
<th>Real-World Kitchen Assessment Score, ρ</th>
<th>VE Score, ρ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clinical Variables</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>−0.30*</td>
<td>−0.35*</td>
</tr>
<tr>
<td>Days from stroke onset</td>
<td>−0.18</td>
<td>−0.12</td>
</tr>
<tr>
<td>Motricity Index (arms)</td>
<td>0.17</td>
<td>−0.06</td>
</tr>
<tr>
<td>Barthel ADL Index</td>
<td>0.48‡</td>
<td>0.40†</td>
</tr>
<tr>
<td>Cognitive Tests</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mini Mental State Examination</td>
<td>0.46†</td>
<td>0.45‡</td>
</tr>
<tr>
<td>Sheffield Aphasia Screening Test</td>
<td>0.08</td>
<td>0.40‡</td>
</tr>
<tr>
<td>Test</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Star Cancellation</td>
<td>0.44†</td>
<td>0.53‡</td>
</tr>
<tr>
<td>Rey Figure Copying</td>
<td>0.49‡</td>
<td>0.49†</td>
</tr>
<tr>
<td>VOSP Object Decision</td>
<td>0.44†</td>
<td>0.35*</td>
</tr>
<tr>
<td>VOSP No. Location</td>
<td>0.46†</td>
<td>0.29*</td>
</tr>
<tr>
<td>RPAB Sequencing Pictures</td>
<td>0.51‡</td>
<td>0.18</td>
</tr>
<tr>
<td>Rey Figure Recall</td>
<td>0.29</td>
<td>0.12</td>
</tr>
<tr>
<td>RBMT Story Recall</td>
<td>0.05</td>
<td>0.22</td>
</tr>
<tr>
<td>TEA Tone Counting</td>
<td>0.11</td>
<td>0.04</td>
</tr>
<tr>
<td>Kimura Box</td>
<td>−0.19</td>
<td>−0.32*</td>
</tr>
<tr>
<td>10-Hole Peg Test (time)</td>
<td>−0.47†</td>
<td>−0.17</td>
</tr>
</tbody>
</table>

*P<0.05; †P<0.01; ‡P<0.001.

mainly used their dominant hand (paretic side in 29 cases) and 10 used their nondominant hand.

The scores for the real world and virtual environment tasks were significantly but not strongly correlated (Spearman’s ρ=0.30; P<0.05). Real-world independence was greater: the mean difference between real world and virtual environment scores was 7.9 (standard deviation, 11.3; range, −9.5 to 38.6). A scatterplot (Figure 2) shows that many participants scored maximally in the real-world kitchen assessment but scored less than maximally in the virtual environment.

Validity was assessed in terms of whether similar factors predicted performance in the real world and virtual environment (Table 3). Both real and virtual performance scores correlated with age, Barthel ADL, Mini Mental State Examination scores, and on tests of visuospatial perception. Real world but not virtual environment performance was associated with arm function and sequencing ability. Virtual environment but not real-world performance was associated with language function and praxis.

There was little association between error patterns when participants attempted to make a hot drink in the real world and virtual environments (Table 4). The mean number of individual errors on real-world performance was 1.95 compared with 3.70 in the virtual environment (Wilcoxon Signed Ranks test z=2.14; P<0.05). Some participants demonstrated errors suggestive of visual inattention in the real world but not in the virtual environment, and vice versa. Certain mistakes could only be made in the real world (such as spilling water onto an electric cable), and certain mistakes were likely to be caused by interface problems (such as when the user attempted to speak to the virtual environment expecting an answer, or when a stirring action of the stylus was interpreted as alternating selection and de-selection of an object), or if there were technical problems (such as freezing of the virtual environment program).

**Discussion**

Our virtual environment was feasible for use in a stroke rehabilitation unit, performance of hot drink-making in the real and virtual worlds were correlated, and the real-world tasks and virtual tasks were sensitive to similar stroke-related impairments. Taken alone, these findings would indicate that our virtual environment may be a useful rehabilitation tool for patients undergoing stroke rehabilitation in hospital. However, making a virtual hot drink was more difficult than making a hot drink in a rehabilitation kitchen, and it was evident from the comparison of the video recordings that people with stroke made different mistakes when making a real and virtual hot drink. Therefore, despite appearing to resemble each other, virtual and real hot drink-making are qualitatively different tasks for stroke patients. The difference between real and virtual tasks has not previously been examined in rehabilitation after brain injury.

One explanation for the difference in difficulty between real and virtual hot drink-making may simply be because many of our participants were unfamiliar with computers, because we found that interface and technical problems contributed to the difference between real and virtual performance. In our extensive developmental work using a user-centered design process,15 we had aimed to develop a system that was suitable for users of this type, and this had informed our choice of a simple, nonimmersive system. However, we
did not test it using an age- and education-matched control group to explore this possibility. Another explanation for the difference between the difficulty between real and our virtual hot drink-making, supported by our findings, is that the virtual task may be inherently more sensitive to stroke deficits such as asapha (each user has to be given instructions of some sort) and dyspraxia (the user has to manipulate a stylus). With either explanation, virtual and real-world hot drink-making tasks are qualitatively different, and so training one task may not lead to changes in performance in the other. Further design work or alternative strategies using different technologies might improve the similarity between real and virtual tasks. One approach would be to use more sophisticated immersive systems, using data gloves, haptics, and headset displays. Case studies have found positive acceptance of these systems, although some users experienced difficulty in using input devices to navigate around a virtual environment. Another way around the problem of creating a more naturalistic interface to a virtual environment that requires the same body functions as the real world task is to use “mixed reality” environments. In these, real objects are manipulated to control their counterparts in the virtual environment, instead of the un-naturalistic interface of the computer touch screen. Such mixed reality environments should still have the potential educational benefits of safety, ease of use, consistency, controllability, repeatability, ease of monitoring, and motivation. They would also have a greater potential to train motor skills and praxis.

Despite the fact that our virtual task was more difficult than the real-world task, at least it simulated the task. Furthermore, by our choice of hardware, our system was portable and therefore flexible in use and inexpensive, making it easily replicable elsewhere. Although further development is needed, our virtual environment may nevertheless be a valuable rehabilitation tool for some patients aiming at making a hot drink, because it retains many of the potential educative benefits of the virtual environment, such as the ability to practice the task repeatedly and in safety, and encouraging error-free learning. We argue that it is important to test feasible systems in clinical practice while being aware of the need to develop potentially better ones, which themselves should be clinically evaluated in due course.

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Disclosures
None.

References


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