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ORIGINAL REPORT

EXERCISES FOR PARETIC UPPER LIMB AFTER STROKE: A COMBINED VIRTUAL-REALITY AND TELEMEDICINE APPROACH

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Objective: **Telerehabilitation enables a remotely controlled programme to be used to treat motor deficits in post-stroke patients. The effects of this telerehabilitation approach were compared with traditional motor rehabilitation methods.**
Design: **Randomized single-blind controlled trial.**
Patients: **A total of 36 patients with mild arm motor impairments due to ischaemic stroke in the region of the middle cerebral artery.**
Methods: **The experimental treatment was a virtual reality-based system delivered via the Internet, which provided motor tasks to the patients from a remote rehabilitation facility. The control group underwent traditional physical therapy for the upper limb. Both treatments were of 4 weeks duration. All patients were assessed one month prior to therapy, at the commencement and termination of therapies and one month post-therapy, with the Fugl-Meyer Upper Extremity, the ABILHAND and the Ashworth scales.**
Results: **Both rehabilitative therapies significantly improved all outcome scores after treatment, but only the Fugl-Meyer Upper Extremity scale showed differences in the comparison between groups.**
Conclusion: **Both strategies were effective, but the experimental approach induced better outcomes in motor performance. These results may favour early discharge from hospital sustained by a telerehabilitation programme, with potential beneficial effects on the use of available resources.**

Key words: stroke, upper extremity, telemedicine, virtual reality.

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INTRODUCTION

Telerehabilitation is the remote delivery of a variety of rehabilitative services through telecommunication technology. This particular application of telemedicine exploits several aspects of rehabilitative medicine at a distance: tele-monitoring (patient assessment functioning and clinical management), tele-therapy, tele-consultation, tele-mentoring and tele-education for professionals and caregivers (1).

Tele-therapy, that is managing therapies remotely, represents the opportunity to convey therapeutic interventions at a distance for subjects with disabilities due to various injuries (2–5). In this regard, several disabilities due to neurological lesions might benefit from the increase in frequency of treatment that could be provided via telemedicine without the systematic displacement of therapist or patient.

On the other hand, several National Health System guidelines recommend a reduction in the duration of patients' stays in hospital in order to minimize expenditure; with this in mind telemedicine could be utilized in facilitating early discharge support. A recent review of early discharge support post-stroke illustrated that patients with mild to moderate disability were significantly less likely to be dead or dependent by the time of their scheduled follow-up, in comparison with those who received conventional care (6).

Craig et al. (7, 8) demonstrated the possibility of managing neurological examination utilizing telemedicine with the same reliability as face-to-face assessment, while for tele-therapy there is a lack of evidence of its effectiveness, probably due to the limited research in this field.

In 2001 we performed an initial study with 5 post-stroke patients connected and treated at home by means of a virtual reality (VR) based prototypal system working on digital lines (9). Data from that study showed an improvement in patient arm motor performance after the telerehabilitation trial and a positive tele-interaction between the patient and the therapist.

To verify this preliminary evidence, we conducted a randomized controlled study with a larger group of post-stroke patients. A new VR-based system, working via low-cost Internet connection, was compared with traditional physical therapy supplied in the local health-district.

SUBJECTS AND METHODS

The study group comprised 36 patients (21 men, 15 women) mean age 65.2 (standard deviation (SD) 7.8) years, with mild to intermediate arm motor impairment (according to the Fugl-Meyer Upper Extremity sub-score ranging from 30 to 55).

Patients were affected by a single ischaemic stroke in the region of the left (16 subjects) and the right (20 subjects) middle cerebral

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artery. They were recruited 7–32 months after the ischaemic event (mean 13.3 (SD 5.5) months). Subjects with clinical evidence of cognitive impairment, such as apraxia (score lower than 62 points at the De Renzi Test), neglect and language disturbances interfering with verbal comprehension (more than 40 errors in the Token test) were excluded from the study.

After the enrolment informed consent was obtained and the 36 selected patients were assigned to 2 groups according to a simple randomization technique using sequentially numbered, opaque sealed envelopes: one group was treated at home with the telerehabilitation system (18 subjects, Tele-rehab group), the other group was treated with conventional physiotherapy in the local health-district (18 subjects, Control group). The envelopes containing the paper sheet with the type of treatment and a sheet of carbon paper were obscured with aluminium foil, shuffled, then numbered sequentially and placed in a plastic container, in numerical order, ready to use for the allocation. Allocation was performed by the therapist coordinator of the hospital where the equipment for the telerehabilitation programme was hosted. The patients were in the charge of the health district, so the coordinator was not involved, as care provider, in the patients' rehabilitation programme.

Descriptive data for the 2 groups are shown in Table I.

Both treatments lasted 1 h a day, 5 days a week for one month.

The motor deficit and the functional activities of the upper extremity were assessed with the Fugl-Meyer scale for the upper extremity (Fugl-Meyer UE) and the ABILHAND scale (10, 11). In addition, spasticity of the arm was determined with the Ashworth scale (12). The timing of assessments was: one month prior to starting therapy (T0), at the commencement of (T30) and at the termination of the therapies (T60) and, finally, one month after termination (T90). The examining neurologist was blind to the treatments administered to the patients.

The protocol was approved by the local ethics committee. Written consent was obtained from all participants.

The telerehabilitation system (VRRS.net®) was developed at the Massachusetts Institute of Technology (Cambridge, MA, USA) and consisted of 2 dedicated personal computer (PC)-based workstations, one located at the patient's home and the second at the rehabilitation hospital. The VRRS.net® generated a VR environment, in which the patients executed the motor tasks, coupled with a videoconference tool. The connection procedure was based on a TCP/IP protocol via broadband access (ADSL) to the Internet. The VRRS.net® integrated high-quality videoconferencing permitted the remote control of the patient's video-camera mobility in order to observe the patient's movement during the rehabilitation tasks (Fig. 1).

The VRRS.net® was equipped with a 3D motion tracking system (Polhemus 3Space Fastrack, Vermont, USA) to record arm movements via a magnetic receiver attached to a real object. The system transformed the receiver into a virtual image (virtual object), which changed position on the screen according to the motion of the receiver.

Five virtual tasks, comprising simple arm movements, were devised for training the patient's left or right arm deficits. During the rehabilitation session, the patient moved the real object following the trajectory of the corresponding virtual object displayed on the computer screen in accordance with the requested virtual task (Fig. 2).

The subject could see not only his or her movement, but also the correct trajectory pre-recorded in the virtual scene (virtual teacher).

Table I. *Descriptive data for the 2 groups after randomization*

	Tele-rehab group $n=18$	Control group $n=18$	p-value
Age, years, mean (SD)	66.0 (7.9)	64.4 (7.9)	0.474
Sex, men/women	11/7	10/8	0.720
Months from lesion to enrolment, months, mean (SD)	14.7 (6.6)	11.9 (3.7)	0.150
Side of stroke, right/left	10/8	10/8	

SD: standard deviation.

Fig. 1. Therapist telerehabilitation equipment (VRRS.net®). The therapist can view the virtual motor task and the patient performance on the same screen during the tele-interaction.

In addition, the therapist provided the patient with information about the tasks' exactness through the videoconferencing system.

Prior to entering the study, the patients were trained to utilize the computerized rehabilitation system, to locate the magnetic receiver correctly, and to execute the requested motor tasks adequately.

Control group subjects, treated with conventional physical therapy, were asked to perform specific exercises for the upper limb with a strategy of progressive complexity. First, they were requested to control isolated motions without postural control, then postural control was included and, finally, complex motion with postural control was practiced. For example, patients were asked to touch different targets arranged in a horizontal plane in front of them; to manipulate different objects; to follow trajectories displayed on a plane; and to recognize different arm positions.

The exercises were chosen by the physical therapist, in relation to the functional assessment and patient needs.

Statistics

A t-test was applied to assess differences between groups in descriptive data after randomization. The Wilcoxon test and the Mann-Whitney U

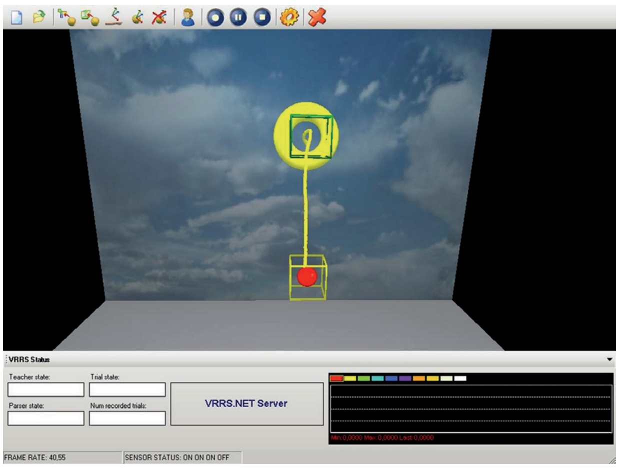

Fig. 2. A representative "virtual" reaching motor task displayed on the patient's personal computer (PC) monitor. The patient, by moving the receiver (corresponding to the virtual red sphere) with the affected arm, has to reach the centre of a yellow virtual doughnut from a starting position (yellow wireframe cube) according to the displayed trajectory.

statistics were used to test for differences within and between groups, respectively, in the Fugl-Meyer UE and the Ashworth scale, at every time interval. Effect sizes were calculated for the Fugl-Meyer UE and Ashworth scales after the treatment and at follow-up (T60 and T90, respectively) and indexed using effect size r (13). According to Cohen (14), a large effect is represented by an of at least 0.50, a moderate effect by 0.30, and a small effect by 0.10. A positive value for effect size indicates that the effect is in the hypothesized direction and a negative value indicates that the effect is in the opposite direction.

ABILHAND results were analysed using WINSTEPS Rasch software and the *t*-tests were applied to the logits in order to measure the statistical significance between groups at every time interval.

Statistical significance was considered at $p \leq 0.05$.

RESULTS

No significant differences (*t*-test) in descriptive data were found between groups after the randomization (Table I).

All patients completed the study and they did not experience problems in handling the VRRS.net® system. The video-conferencing included a complete assistance by the physiotherapist, who eventually could remotely control all of the commands.

A reduction in broadband quality was reported at times, with a slowing of the data flow and blurring of the images. Occasionally there was an unexpected interruption in the connection between the 2 workstations.

Table II shows the mean scores and effect size of the Fugl-Meyer UE and Ashworth assessment scales for the affected arm in both groups.

In both groups mean values of the assessment scales did not change significantly in the month prior to the therapy (from T0 to T30). On the other hand, we observed a significant improvement in all fields after the treatment, in both groups. Furthermore, a significant improvement in the Fugl-Meyer UE was seen in the Telerehab group compared with the control group (Fig. 3).

Finally, in the follow-up phase (from T60 to T90), both groups substantially maintained the benefits achieved. According to Cohen (14), we observed in the Fugl-Meyer UE and Ashworth, respectively, a moderate and small effect of the telerehabilitation treatment compared with the traditional motor therapy conducted in the health district.

For our patients after stroke, the measure of perceived difficulty for the ABILHAND items is shown in Table III. The table also shows the standard error of the item difficulty activities and some fit statistics.

In our calibration, the measures of perceived difficulty for the 23 items were related to those reported by Penta et al. (11).

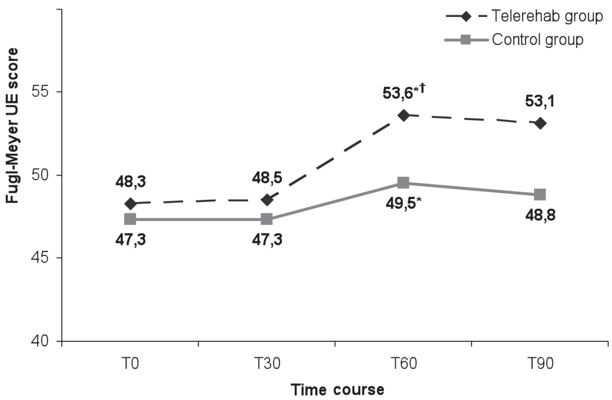

Fig. 3. Fugl-Meyer Upper Extremity (Fugl-Meyer UE) scores, in experimental (Telerehab) and control groups. *Statistical significance for Wilcoxon test, $p<0.05$. †Statistical significance for Mann-Whitney *U* test, $p<0.05$.

Poor fit measures were obtained for the items "Cutting one's nails" (d) and "Tearing open a pack of chips" (l).

The box-plots of the logits for each assessment time, administering the ABILHAND scale in the Telerehab and Control group, are shown in Fig. 4. A statistically significant difference between groups was seen at the first 3 assessment times (T0: $t=-2.1385$, *p*-value = 0.04003; T30: $t=2.7067$, *p*-value = 0.01059; T60: $t=-2.7181$, *p*-value = 0.01048) but not at the final follow-up (T90: $t=-1.3683$, *p*-value = 0.1810). Finally, no differences were found within groups, in the comparison of the ABILHAND results during the time course of the study.

DISCUSSION

This study compared the effects of a traditional rehabilitation therapy with an innovative rehabilitative VR-based technique provided at distance by telemedicine.

After the randomization procedure, the groups' results completely balanced, indicating that they represented the same population of stabilized patients after stroke.

Both therapies resulted in the effective treatment of arm motor deficits due to an ischaemic stroke, with a specific effect of VR-based therapy on motor performance, as seen in comparison between groups at T60. These results confirmed the previous evidence seen in a smaller group of post-stroke patients treated at home with telerehabilitation (9, 15). In our

Table II. *Functional results of studied groups, reported as means (standard deviations)*

	Fugl-Meyer UE			Ashworth		
Assessment time	Telerehab group	Control group	Effe ct size, r	Telerehab group	Control group	Effect size, r
T0	48.3 (7.2)	47.3 (4.5)		2.2 (1.6)	1.3 (1.0)	
T30	48.5 (7.8)	47.3 (4.6)		2.4 (1.9)	1.3 (1.0)	
T60	53.6 (7.7)*†	49.5 (4.8)*	0.30	1.7 (2.0)*	1.0 (0.8)*	0.22
T90	53.1 (7.3)	48.8 (5.1)	0.32	2.0 (2.0)	1.1 (0.9)	0.28

*Statistical significance for Wilcoxon test, $p<0.05$.

†Statistical significance for Mann-Whitney *U* test, $p<0.05$.

Table III. *ABILHAND calibration for the enrolled post-stroke patients*

Items	Difficulty, logits	SE, logits	INFIT mean square	OUTFIT mean square	RPM
Hammering a nail	2.55	0.28	1.15	1.49	0.14
Threading a needle	1.75	0.19	0.74	0.75	0.54
Peeling potatoes with a knife	1.92	0.20	0.93	1.00	0.66
Cutting one's nails	–0.01	0.20	1.41	1.81	0.40
Wrapping up gifts	2.48	0.23	1.21	1.14	0.58
Filing one's nails	–0.73	0.25	0.78	0.75	0.53
Cutting meat	1.13	0.16	0.82	0.83	0.68
Peeling onions	0.70	0.20	0.86	0.85	0.63
Shelling hazel nuts	0.93	0.24	1.33	1.20	0.74
Opening a screw-topped jar	0.69	0.18	1.02	0.97	0.52
Fastening the zipper of a jacket	0.57	0.17	1.04	1.02	0.59
Tearing open a pack of chips	0.42	0.17	1.36	1.51	0.35
Buttoning up a shirt	0.45	0.17	1.03	0.91	0.61
Sharpening a pencil	–1.43	0.34	1.11	0.86	0.46
Spreading butter on a slice of bread	–0.61	0.22	0.85	0.93	0.49
Fastening a snap (e.g. jacket, bag)	–1.46	0.28	0.80	0.83	0.42
Buttoning up trousers	–0.78	0.22	0.88	0.76	0.45
Taking the cap off a bottle	1.02	0.17	0.89	0.80	0.73
Opening mail	–1.32	0.27	0.97	0.82	0.37
Squeezing toothpaste on a toothbrush	–2.72	0.43	0.77	0.62	0.30
Pulling up the zipper of trousers	–0.05	0.18	0.94	0.71	0.60
Unwrapping a chocolate bar	–0.93	0.23	0.82	0.78	0.45
Washing one's hands	–4.6	1.01	1.02	1.09	0.06

INFIT: information-weighted fit statistic; OUTFIT: outlier sensitive fit statistic; RPM: point-measure correlation coefficient; SE: standard error.

VR setting, patients were provided with information about their arm movements during the performance (knowledge of performance) of motor skills in the form of graphical representation of their end-effector and the "virtual teacher" movement on their monitor. Giving feedback of kinematics of the hand path seems to be advantageous for patients to exploit neuro-physiological learning mechanisms, such as "learning by imitation" (16) and "trial and error" (17). Furthermore, the instructions about motor performance imparted by the therapist through videoconferencing promoted the so-called "supervised learning" mechanism.

A second kind of feedback (knowledge of results) was a reward delivered when the task performance score surpassed a pre-established threshold. All these phenomena contributed to generating the basis for the "reinforcement learning" mechanism that has been demonstrated to be beneficial in human motor learning (18–20) as well as in post-stroke patients (17, 21–26).

These data confirm that subjects exposed to a remotely controlled treatment in a virtual environment, could achieve a moderately better motor performance with the same amount of therapy, without moving from their home.

We have also shown that telerehabilitation represents a feasible method to treat stroke motor impairments without major technical problems or handling system difficulties for the patients (5, 9).

In addition, the artificial patient-therapist interaction did not interfere with the process of motor recovery, as demonstrated by the progress of the clinical scale scores and confirmed the effectiveness of a late therapy, in stabilized stroke survivors (27).

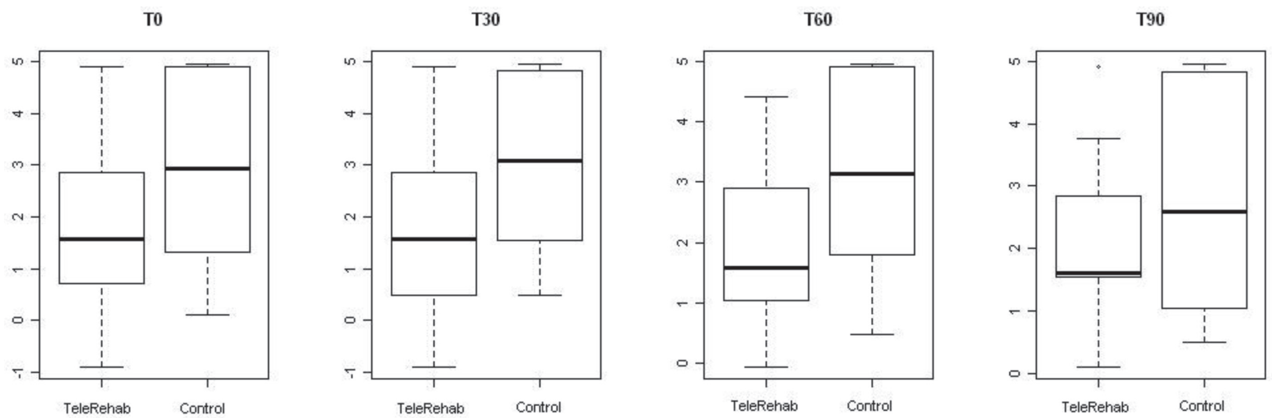

Fig. 4. Box-plots of ABILHAND results at all assessment times for both Telerehab and Control groups.

Both groups retained all the outcome values 30 days after the termination of treatment, indicating that both strategies induce changes in motor behaviour that endure with time.

These observations may underestimate the effect of the physical presence of the therapist and may reinforce the hypothesis that adequate feedback and the supply of real-time therapist interaction may represent the key factors in the processes of motor recovery.

In both groups, the subjective perceived manual ability showed a constant, although small, improvement during the whole time course of the study, with maintenance at the follow-up, as indicated by the analysis of the reported answers in the ABILHAND scale. These results, together with the improvement in the Fugl-Meyer UE, demonstrate how the continuity of care bettered objective and subjective outcomes in discharged and stabilized stroke patients.

In conclusion, the results of this study indicate that mild to intermediate post-stroke patients may undergo a telerehabilitation programme so improve their motor deficits. This fact may favour an early discharge from hospital and a subsequent rehabilitative intervention at home, which do not compromise clinical outcomes after a stroke and may have beneficial effects on quality of life.

Further research is necessary to evaluate the cost-effectiveness of this type of approach in telemedicine.

REFERENCES

1. Forducey PG, Ruwe WD, Dawson SJ, Scheideman-Miller C, McDonald NB, Hantla MR. Using telerehabilitation to promote TBI recovery and transfer of knowledge. NeuroRehabil 2003; 18: 103–111.
2. Burns RB, Crislip D, Daviou P, Temkin A, Vesmarovich S, Anshutz J. Using telerehabilitation to support assistive technology. Assistive Technol 1998; 10: 126–133.
3. Reinkensmeyer DJ, Pang CT, Nessler JA, Painter CC. Web-based telerehabilitation for the upper extremity after stroke. IEEE Trans Neural Syst Rehabil Eng 2002; 10: 102–108.
4. Burdea G, Popescu V, Henz V, Colbert K. Virtual reality based orthopedic telerehabilitation. IEEE Trans Neural Syst Rehabil Eng 2000; 8: 430–432.
5. Piron L, Tonin P, Atzori AM, Zanotti E, Trivello E, Dam M. Virtual environment system for motor tele-rehabilitation. In: Westwood JD, Hoffman HF, Robb RA, Stredney D, editors. Medicine meets virtual reality 2002. Amsterdam: IOS Press; 2002, p. 355–361.
6. Langhorne P, Widen-Holmqvist L. Early support discharge after stroke. J Rehabil Med 2007; 39: 103–108.
7. Craig JJ, McConville JP, Patterson VH, Wootton R. Neurological examination is possible using telemedicine. J Telemed Telecare 1999; 5: 177–181.
8. Craig J, Patterson V, Russell C, Wootton R. Interactive videoconsultation is a feasible method for neurological in-patient assessment. Eur J Neurol 2000; 7: 699–702.
9. Piron L, Tonin P, Trivello E, Battistin L, Dam M. Motor telerehabilitation in post-stroke patients. Med Inform Internet Med 2004; 29: 119–125.
10. Fugl-Meyer R, Jaasko L, Leyman L, Olsson S, Steglind S. The post-stroke hemiplegic patient. A method for evaluation of physical performance. Scand J Rehab Med 1975; 7: 13–31.
11. Penta M, Tesio L, Arnould C, Zancan A, Thonnard JL. The ABILHAND Questionnaire as a measure of manual ability in chronic stroke patients Rasch-based validation and relationship to upper limb impairment. Stroke 2001; 32: 1627–1634.
12. Bohannon RW, Smith MB. Interrater reliability of a modified Ashworth scale of muscle spasticity. Phys Ther 1987; 67: 206–207.
13. Rosenthal R, Rosnow RL Essentials of behavioral research: methods and data analysis. 2nd edn. New York, NY: McGraw-Hill; 1991.
14. Cohen J, editor. Statistical power analysis for the behavioral sciences. 2nd ed. Hillsdale, NJ: Lawrence Erlbaum Associates; 1988.
15. Piron L, Tonin P, Cortese F, Zampolini M, Piccione F, Agostini M, et al. Post-stroke arm motor telerehabilitation web-based. Proceedings of IEEE 5th International Workshop Virtual Rehabilitation. New Jersey: IET (IEEE) Press; 2006, p. 145–148.
16. Russon AE. Learning by imitation: a hierarchical approach. Behav Brain Sci 1998; 21: 667–684.
17. Piron L, Tonin P, Piccione F, Iaia V, Trivello E, Dam M. Virtual environment training therapy for arm motor rehabilitation. Presence 2005; 6: 732–740.
18. Winstein CJ. Knowledge of results and motor learning implications for physical therapy. Phys Ther 1991; 71: 140–149.
19. Young DE, Schmidt RA. Augmented kinematic feedback for motor learning. J Mot Behav 1992; 24: 261–273.
20. Todorov E, Shadmehr R, Bizzi E. Augmented feedback presented in a virtual environment accelerates learning of a difficult motor task. J Motor Behav 1997; 29: 147–158.
21. Winstein CJ, Pohl PS, Cardinale C, Green A, Scholtz L, Waters CS. Learning a partial-weight-bearing skill: effectiveness of two forms of feedback. Phys Ther 1996; 76: 985–993.
22. Cirstea CM, Ptito A, Levin MF. Feedback and cognition in arm motor skill reacquisition after stroke. Stroke 2006; 37: 1237–1242.
23. Woldag H, Hummelsheim H. Evidence-based physiotherapeutic concepts for improving arm and hand function in stroke patients: a review. J Neurol 2002; 249: 518–528.
24. Piron L, Tonin P, Atzori AM, Zucconi C, Massaro C, Trivello E, et al. The augmented-feedback rehabilitation technique facilitates the arm motor recovery in patients after a recent stroke. Stud Health Technol Inform 2003; 94: 265–267.
25. You SH, Jang SH, Kim YH, Hallett M, Ahn SH, Kwon YH, et al. Virtual reality-induced cortical reorganization and associated locomotor recovery in chronic stroke: an experimenter-blind randomized study. Stroke 2005; 36: 1166–1171.
26. Holden MK. Virtual environments for motor rehabilitation: review. Cyberpsychol Behav 2005; 8: 187–211.
27. Page SJ, Gater DR, Bach-Y-Rita P. Reconsidering the motor recovery plateau in stroke rehabilitation. Arch Phys Med Rehabil 2004; 85: 1377–1381.