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Recovery of somatosensory and motor functions of the paretic upper limb in patients after stroke: Comparison of two therapeutic approaches

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Background: Frequent and extensive disturbances to the somatosensory and motor hand functions after stroke are common. This study explores a new therapeutic approach that may improve the effectiveness of rehabilitation for these upper limb impairments. **Objective:** To assess the effect of rehabilitation combining standard therapy and somatosensory stimulation on sensorimotor hand functions. To compare the effect of this method with the standard method of rehabilitation. **Methods:** Two groups of patients were used to compare the effect of standard therapy (group A, n = 15, age = 59.8 ± 9.4 years), and the effect of therapy with targeted somatosensory stimulation (group B, n = 15, age = 65.5 ± 8.2). The groups consisted of patients after an ischemic stroke in post-acute phase, with hemiparesis, aged from 45 to 75 years, both men and women. The methods used to assess patients comprised a neurological clinical examination, two batteries of tests of somatosensory function (Rivermead Assessment of Somatosensory Performance, Fabric Matching Test), two batteries of tests of motor function (Nine Hole Peg Test, Test of Manipulation Functions), and activities of daily living assessment. **Results:** The results show that before therapy a deficit of somatosensory function occurred on the paretic upper limb in more than 50% of patients in both groups. Motor functions were impaired more frequently than somatosensory functions. Somatosensory stimulation therapy had an enhanced improvement of somatosensory functions, especially tactile discrimination of the object surface. **Conclusions:** Major improvement, particularly of tactile discrimination sensation, occurred in group B, where therapy focused on somatosensory deficit was applied. We did not show that such considerable improvement in discrimination sensation in group B was associated with any change in motor function. Clinical improvement in the motor function of the paretic limb occurred in both samples. However, more significant improvement was evident for the group with standard therapy.

Keywords: stroke, rehabilitation, somatosensory function, motor function, upper limb

Introduction

Disorders of the motor and somatosensory function of the upper limb are frequent clinical symptoms in strokes. Recovery of the somatosensory functions of the upper limb is slower and more complicated than in the lower limb (Carey, Oke, & Matyas, 1996). This can be explained by the fact that therapy is usually focused primarily on the gait and mobility training in order to achieve the patient's mobilization as quickly as possible, and consequently reduce hospitalization costs (Levin, Kleim, & Wolf, 2009). Much less attention has been given to the deficit of somatosensory functions, although the clinicians agree that it is equally important (Yekutiel & Guttman, 1993). Disorders of the somatosensory function of the hand can affect all the main functions of the upper limb, i.e. grasp and manipulation, self-care, occupation, communication and participation in actively providing or accepting kinetic energy (Véle, 2006). Relations between sensory and motor functions have been examined for years. Recently, research has focused on the relationship of these functions to performing the practical activities of daily living. It is apparent any disorder of somatosensory function can be an important cause of functional disorder, particularly of the hand (Carr & Shepherd, 2010). The significant role of sensation is especially

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apparent when checking tweezer or pinch grip, as well as the capacity to maintain and adjust the appropriate strength without eye control (Blennerhassett, Carey, & Matyas, 2008; Blennerhassett, Matyas, & Carey, 2007), discrimination of the surfaces of objects held in the hand, and adaptation to sensory conflict conditions such as rough surfaces (Carey et al., 2006). This can result in disuse syndrome of the limb and further deterioration in motor function (Smania, Montagnana, Faccioli, Fiaschi, & Aglioti, 2003; Yekutiel & Guttman, 1993).

A routine check-up does not reveal the occurrence of all disorders of somatosensory function. Some authors assume that the observation of somatosensory functions is not necessary to predict the recovery of impaired function and that it is difficult to evaluate it in an unbiased way (Lincoln et al., 1991). This is because even slight somatosensory disorders can affect clinical outcomes, as well as the functional reorganization/rearrangement of sensory areas adjacent to the damaged tissue (Blennerhassett, Carey, & Matyas, 2006; Carey, Matyas, & Oke, 2002; Rossini et al., 1998).

Presumably, sensory afference forms an integral part necessary to the maintenance of cortical representation and therefore the function of the upper limb after stroke (Schabrun & Hillier, 2009). The results of neurological imaging studies and clinical studies show the significance of the somatosensory system as an early indicator of motor recovery after stroke (Nelles et al., 1999; Ward & Cohen, 2004). It can be assumed that sensory reorganization/rearrangement can precede and trigger motor reorganization (Weiller, 1998).

In the list of symptoms, disorder of somatosensory function is mentioned in over 65% of patients after stroke. Currently, relatively little is known about how the recovery of somatosensory function proceeds, how long it takes, or whether the extent or type of this disorder correlates to a worse recovery of motor function (Winward, Halligan, & Wade, 2007).

The objective of our work was to compare the degree of adjustment of somatosensory and motor function disorders of the upper limbs before and after therapeutic rehabilitation and compare the effect of this method of somatosensory stimulation with the standard method of rehabilitation for central disorders of motion.

Methods

Participants

The research sample comprised 30 hemiplegic subjects after a middle cerebral artery ischemic stroke, with hemiparesis, aged 45 to 75 (66.66 ± 8.96 years). In all subjects the preferred upper limb was the one on the right side of the body. In 19 individuals left-sided hemiparesis was detected, in 11 subjects there was a right-sided hemiparesis. Each participant was randomly assigned to a group (decided by lots). Group A (undergoing standard therapy) included 15 subjects. Group B (undergoing rehabilitation combining standard therapy and somatosensory stimulation focused on their somatosensory disturbances) included 15 subjects (Table 1). Exclusion criteria were the individual's ability to co-operate, i.e. they were without severe aphasia, without neglect syndrome, hemianopia and without peripheral neuropathy.

This study was agreed to by the ethical board of the Faculty Hospital of Ostrava working in compliance with the effective and legal regulations of the International Conference on the Harmonisation of Technical Requirements for the Registration of Pharmaceuticals for Human Use.

Table 1
Characteristics of the participants

	Group A (n = 15)	Group B (n = 15)
Age (years, mean ± SD)	59.8 ± 9.4	65.5 ± 8.2
Men/women	7/8	8/7
Paretic side left/right	11/4	8/7

Measures

For the assessment, the following clinical and standardized tests were used. Neurological deficit was assessed by means of neurological clinical examination National Institute of Health Stroke Scale (NIHSS; Lyden et al., 1999), supplemented by clinical examination to assess the grade of paresis by means of Mingazzini's test (Ambler et al., 2008) and an examination of muscle tone according to the Modified Ashworth Scale (Bohannon & Smith, 1987).

To assess somatosensory function, we used a battery of tests of the Rivermead Assessment of Somatosensory Performance (abbreviated as RASP) and the Fabric Matching Test (abbreviated as FMT). RASP assesses particular modalities of sensation by means of seven subtests. The test comprises a quantitative scale with a point scoring system to assess the patient's ability to identify the applied stimulus (Winward, Halligan, & Wade, 2000; Busse & Tyson, 2009). The Fabric Matching Test assesses discriminatory tactile sensation. The test comprises a quantitative scale with point scoring system to assess the patient's ability to explore the tested surface (Carey, Oke, & Matyas, 1997).

To assess disorders of motor function, we used the Nine Hole Peg Test (abbreviated as NHPT) and the

Test of Manipulation Functions (abbreviated as TMF). NHPT uses standards discriminating the age and sex of patients. Its criterion is the time in which the tested subject carries out a given task (Mathiowetz, Weber, Kashman, & Volland, 1985; Wade, 1992). The TMF is performed using the special patented construction set "Ministav" (Josef Pech, MD., Nový Jičín, Czech Republic), see Vyskotová and Vaverka (2007) for its detailed description. It uses standards discriminating the age of patients. Its criterion is also the time in which the tested subject carries out a given task (Vyskotová & Macháčková, 2013).

To assess the activities of daily living we used the Barthel Index (abbreviated as BI), which enables international comparison because it is most frequently used in research studies worldwide. The test uses a quantitative scale and point scoring system to assess the patient's ability to carry out given tasks independently. The maximum 100 points is awarded for performing certain tasks without assistance (Mahoney & Barthel, 1965).

Intervention

Patients were assessed by a team of four experienced, certified therapists who had been trained according to the manuals of practice of the particular tests. Patients were assessed at the inpatient department of rehabilitation at the beginning and end of their treatment.

In group A a well-established and regularly used method of rehabilitation for stroke patients (further referred to as "standard") was applied, while in group B, in addition to the standard method of rehabilitation, an additional method with somatosensory stimulation was applied. Therapy was applied 6 days a week for 3–4 weeks (with the duration of 1.5 hours per day). In group B, standard therapy (three times a week) alternated with the method of somatosensory stimulation (the other three days a week). The total time of the therapy was identical for both groups (i.e. 9 hours per week).

Standard therapy

The standard therapy was based mainly on the principles of current neurorehabilitation practice. It is a problem-solving approach to the assessment and treatment of individuals with disturbances of function, movement and postural control due to a lesion of the central nervous system. Standard rehabilitation was carried out in the form of kinesiotherapy and physical therapy. Kinesiotherapy comprised aspects of PNF, myofascial techniques, individual task-oriented therapy and physical conditioning training. Physical therapy involved hydrotherapeutic procedures and electrotherapy (electrical stimulation and distance electrotherapy).

Somatosensory stimulation

Therapy focusing on somatosensory stimulation was aimed at a combination of so-called peripheral approaches and motor-learning principles. The peripheral approaches involve manual soft-tissue methods, differential facilitation of proprioceptors and exteroceptors, and repetitive stimulation by specific stimuli. We preferred a task-oriented approach and to train typically disrupted discriminations that are important in daily living activities. We emphasized patients' motivation and attention, because the human brain responds to meaningful aims. The main principles we used were variability of practice, anticipatory projection and external feedback.

Statistical analysis

The Wilcoxon signed-rank test was used for the comparison of initial and post-treatment values obtained during this study in groups A and B. Although we used the nonparametric test, we used mean and standard deviation for ease of comparison with previous literature. Statistical significance was considered at $p < .05$. For calculations we utilized the statistical program Statistica (Version 8.0., StatSoft, Tulsa, OK, USA).

Results

We compared the results of the neurological, somatosensory, motor and activities of daily living tests at the beginning and end of the rehabilitation (Table 2, 3). All significant differences showed an improved performance at the post-treatment examination.

In the NIHSS, statistically significant improvement occurred in both groups. Similarly there was statistically significant improvement of activities of daily living, assessed by the Barthel Index, in both groups.

Concerning somatosensory function in group A, statistically significant improvement occurred in RASP in the subtests "Surface pressure touch", "Temperature discrimination" and "Statesthesia". In group B there was statistically significant improvement in "Surface pressure discrimination" (assessed by FMT) and in the subtest "Surface localization" (assessed by RASP).

In the motor function of group A, statistically significant improvement occurred in the NHPT. In the TMF there was an improvement in the subtests "Sewing", "Assembling the pyramid" and "Dismantling the pyramid" and "Assembling the mummy" and "Dismantling the mummy". In group B statistically significant improvement occurred in TMF in the subtests "Sewing" and "Dismantling the mummy".

Table 2

Comparison of pre and post-treatment assessments of neurological, somatosensory and activities of daily living functions. Values are in points presented as mean ± SD.

	Group A		Group B	
	Pre-treatment	Post-treatment	Pre-treatment	Post-treatment
NIHSS scale	4.73 ± 2.49	3.13 ± 2.39*	6.27 ± 3.15	3.27 ± 1.87*
Modified Ashworth scale	0.57 ± 1.05	0.83 ± 1.10	1.00 ± 1.09	0.77 ± 0.96
Fabric Matching Test	15.92 ± 12.49	17.86 ± 14.95	13.92 ± 10.15	9.21 ± 9.59*
RASP: sharp/dull discrimination	21.20 ± 4.71	22.40 ± 2.64	19.87 ± 5.41	21.20 ± 4.74
RASP: surface pressure touch	25.73 ± 5.05	27.80 ± 2.60*	26.13 ± 3.83	27.13 ± 3.70
RASP: surface localization	23.27 ± 5.54	24.40 ± 4.27	21.53 ± 7.78	24.40 ± 5.55*
RASP: two-point discrimination	3.27 ± 2.09	3.53 ± 1.77	4.57 ± 1.28	4.31 ± 1.03
RASP: temperature discrimination	23.27 ± 6.06	26.67 ± 3.42*	22.80 ± 6.37	22.73 ± 6.34
RASP: proprioception movement discrimination	27.60 ± 5.72	27.60 ± 5.18	27.67 ± 6.74	28.93 ± 4.13
RASP: proprioception position discrimination	24.00 ± 5.50	26.07 ± 5.38*	24.53 ± 7.15	26.13 ± 5.57
Barthel Index	74.33 ± 29.57	91.33 ± 13.95*	70.00 ± 27.90	100.33 ± 7.19*

*Statistically significant difference between pre- and post-treatment.

Table 3

Comparison of pre and post-treatment assessments of motor functions. Values are in seconds presented as mean ± SD.

	Group A		Group B	
	Pre-treatment	Post-treatment	Pre-treatment	Post-treatment
Nine Hole Peg Test	61.47 ± 22.56	43.65 ± 15.95*	60.79 ± 45.65	46.25 ± 13.94
TMF: Needle – sewing	32.41 ± 12.50	23.16 ± 6.49*	61.28 ± 35.06	31.27 ± 16.68*
TMF: Cube – assembling	4.47 ± 1.95	4.84 ± 5.03	9.73 ± 12.04	22.67 ± 37.01
TMF: Cube – dismantling	2.79 ± 1.59	2.82 ± 3.09	3.81 ± 2.25	7.02 ± 7.62
TMF: House – palmar grasp	9.18 ± 11.20	5.08 ± 5.78	2.45 ± .96	4.62 ± 3.36
TMF: House – finger grasp	1.62 ± 0.42	2.26 ± 1.05	2.38 ± 0.40	2.88 ± 1.35
TMF: Pyramid – assembling	38.61 ± 32.96	20.67 ± 15.00*	36.93 ± 28.60	28.28 ± 20.52
TMF: Pyramid – dismantling	6.25 ± 2.14	4.07 ± 1.31*	9.44 ± 5.10	11.69 ± 15.96
TMF: Mummy – assembling	42.52 ± 15.31	30.74 ± 14.93*	57.14 ± 58.75	33.77 ± 40.55*
TMF: Mummy – dismantling	12.27 ± 3.14	11.87 ± 7.82*	19.13 ± 11.22	21.49 ± 16.64

*Statistically significant difference between pre- and post-treatment.

Discussion

During therapy, changes in the motor deficit of the paretic limb occurred in both groups of patients. The functional neurological deficit assessed by NIHSS decreased in both groups. However, in group A, spasticity and a deterioration of the paresis on the upper limb occurred in some of the patients.

Somatosensory functions tended to improve in both groups. Patients undergoing standard therapy showed improvements in three modalities of tactile sensation, and no improvement in the ability to discriminate different types of surface. Patients who received standard therapy and somatosensory stimulation showed improvement in one modality of tactile sensation and also in their ability to discriminate different types of surface.

Our findings correlate with the findings of other authors which demonstrate that various modalities can be impaired to various extents in a disorder of the CNS (Connell, Lincoln, & Radford, 2008; Shimojo & Shams, 2001). The work of Shimojo and Shams (2001) showed that there is a high degree of interaction, integration and overlapping among the tactile, visual and acoustic modalities of the sensory system. According to Connell et al. (2008) it is somewhat obsolete to consider the independent functioning of individual modalities.

In our study, the evaluation of particular modalities by RASP showed both improvement and deterioration of somatosensory functions to different extents. Connell et al. (2008) stated that the nature of the assessment used is a possible cause for the differing impairment of individual modalities, since it assesses individual modalities separately. Using so-called multiple functional assessment, on the other hand, should result in better harmony and the mutual effect of modalities. In our study we used both separate assessment of modalities (by RASP) and also a so-called functional examination (by FMT) and the results of our research did not confirm this assumption. In this context the results of the patients undergoing standard therapy in modalities of proprioception are interesting because there was statistically significant improvement in their *proprioception position discrimination*. For both groups it can be stated that *proprioception position discrimination* was more impaired than *proprioception movement discrimination*.

In patients undergoing rehabilitation combining standard therapy and somatosensory stimulation, where stimulation focusing on somatosensory deficits was applied there was statistically significant improvement in the ability to discriminate between the quality of surfaces.

Despite the fact that motor functions tended to improve in both groups after neurorehabilitation therapy, there was a large number of patients who were unable to perform some of the motor tests. That indicates the presence of a considerable motor deficit.

In patients undergoing standard therapy, motor skills seemed to improve in grasping and manipulating objects and holding up objects where finger squeeze was required. Improvements in handling objects by assembling and dismantling ("Pyramid" and "Mummy"), in precise bi-digital tweezer grasp (NHPT) and handling with a tri-digital pinch grip in "Sewing" were found statistically significant according to the Wilcoxon test.

In patients undergoing rehabilitation combining standard therapy and somatosensory stimulation, motor skills improved in handling objects by assembling the so-called "Mummy" and in "Sewing".

The groups differed in their results for statistically evaluated changes (see above), where a much more significant improvement was shown in group A. A different result was found in the precise bi-digital tweezer grasp assessed by NHPT. In group B, a minimum of patients was able to manage the test and none achieved the norm. On the other hand, in group A more than 50% of patients managed the test and, although nobody achieved the norm, according to the results of the Wilcoxon test there was statistically significant improvement.

It is well-known that proprioceptive information is part both of the feedback information as well as serving to preset the triggering and control of the course of coordinated motion (Véle, 2006; Yekutiel, 2002). Some studies declare statesthesia as a reliable parameter/variable for prognosis regarding the degree/extent of long-term adjustment of the motor functions and a strong correlation between statesthesia and the recovery of motor skills of the hemiplegic upper limb (Carey et al., 1996). The outcomes of our study also suggest linkage between statesthesia and fine motor skills of the hand. In the observed period, statistically significant improvement of statesthesia was registered in patients undergoing standard therapy. In those patients undergoing rehabilitation combining standard therapy and somatosensory stimulation, there was no statistically significant improvement of statesthesia, and patients improved in just two out of ten of the motor subtests used.

There was a difference in the proportionality of the applied therapy in both groups. In the experimental group, part of the standard therapy was replaced by the somatosensory function target therapy, while the control group underwent solely therapy for the recovery of motor functions. The results show the impact of the above mentioned differentiated approach. While the experimental group showed improvement not only at the level of detecting particular modalities but also at the level of discrimination, the control group showed a significant improvement in motor functions, but none at all in discrimination. The results show that, contrary to proprioception, tactile sensation at the level of discrimination does not correlate so closely with motor functions.

In activities of daily living, assessed by the Barthel Index, there was statistically significant improvement in both groups. Compared to motor functions there is a considerable difference, since all patients were able to perform the test.

From the results given above it appears that there are different mechanisms of adjustment for some motor and somatosensory functions in each of the studied groups.

Conclusions

A deficit of somatosensory function of the paretic hand occurred in over 50% of patients in both groups. Motor functions of the paretic hand were impaired more frequently than somatosensory functions. A major deficit was found in the precise bi-digital grasp, tri-digital pinch grip and in holding up an object. In the subjects of both groups *proprioception movement discrimination* was impaired much less than *proprioception position discrimination*. Thus we suggest assessing both modalities, *proprioception position discrimination* and *proprioception movement discrimination* when proprioception is to be tested. Major improvement, particularly of tactile discrimination sensation, occurred in the group in which therapy focused on somatosensory deficit was applied. After application of therapy, clinical improvement of the motor functions of the paretic limb occurred in both samples. However, more significant improvement was evident for the group with standard therapy. The standard clinical neurological examination is usually unable to detect the dynamics of adjustment of the motor and somatosensory function in patients after an ischemic stroke.

Thus we recommend use of sufficiently sensitive motor and somatosensory tests in patients after stroke. As the results of our study show, a clinically detected deficit should even be observed by means of appropriate imaging methods and the results gained should be correlated.

Conflict of interest

There were no conflicts of interest.

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