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ORIGINAL COMMUNICATION

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Using musical instruments to improve motor skill recovery following a stroke

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Abstract In previous studies, it was shown that there is a need for efficient motor rehabilitation approaches. For this purpose, we evaluated a music-supported training program designed to induce an auditory–sensorimotor co-representation of movements in 20 stroke patients (10 affected in the left and 10 in the right upper extremity). Patients without any previous musical experience participated in an intensive step by step training, first of the paretic extremity, followed by training of both extremities. Training was applied 15 times over 3 weeks in addition to conventional treatment. Fine as well as gross motor skills were addressed by using either a MIDI-piano or electronic drum pads. As a control, 20 stroke patients (10 affected left and 10 right) undergoing exclusively conventional therapies were recruited. Assignment to the training and control groups was done pseudo-randomly to achieve an equal number of left- and right-affected patients in each group. Pre- and post-treatment motor functions were monitored using a computerized movement analysis system (Zebris) and an established array of motor tests (e.g., Action Research Arm Test, Box & Block Test). Patients showed significant improvement after treatment with respect to speed, precision and smoothness of movements as shown by 3D movement analysis and clinical motor tests. Furthermore, compared to the control subjects, motor control in everyday activities improved significantly. In conclusion, this innovative therapeutic strategy is an effective approach for the motor skill neurorehabilitation of stroke patients.

Key words auditory–sensorimotor integration · plasticity · neurorehabilitation · stroke · music therapy

Motor impairment following stroke is one of the most important factors preventing patients' participation in everyday activities and limiting their vocational rehabilitation. Because the effectiveness of classic approaches, e.g., that developed by Bobath, has been found to be quite limited, there is a need for efficient motor rehabilitation approaches [1–5]. In this regard, data has accumulated indicating that repetitive massed practice of movements leads to improvements [6, 7]. For example, in constraint-induced therapy (CI) use of the impaired extremity results from immobilizing the healthy extremity for several hours per day.

This procedure has been shown to lead to functional reorganization as demonstrated by transcranial magnetic stimulation and PET [8–11]. Other studies show, that plastic reorganization of neuronal networks may play an important role in recovery after brain injuries, ischemic lesions after stroke, or degeneration processes [12–17].

Importantly, animal studies have shown that cortical plasticity is increased by the behavioural relevance of the stimulation and its motivational value [18–23]. Previous studies have shown very rapid plastic adaptation due to music performance which is not restricted to cortical motor areas but also involves auditory and integrative auditory–sensorimotor circuits [24, 25]. Because of the high motivational value of music and in light of the above mentioned studies on auditory–sensorimotor coupling, we designed a study that entailed active music making in the rehabilitation of stroke patients. Specifically, patients underwent, in addition to conventional therapy in a rehabilitation hospital, daily sessions in which they produced tones, scales and simple melodies on an electronic piano or an electronic drum set (emitting piano tones). In addition to the well-known benefit of repetitive movements we hypothesized that patients would benefit from the immediate auditory feedback to their movements and, possibly, from processes of audio-motor integration [24].

Methods

Patients

A total of 40 inpatients of a neurological rehabilitation hospital participated, all suffering from a moderate impairment of motor function of upper extremities, as evidenced by clinical examination, following a stroke. In order to be eligible for the training study, inclusion criteria were specified similar to those adopted for constraint-induced movement therapy [7]. In particular, (a) patients had to have residual function of the affected extremity, i.e., had to be able to move the affected arm without help from the healthy side, and to move the index finger without help from the healthy hand. Moreover, (b) an overall Barthel Index over 50 (possible score 100) [26] was demanded and (c) performance on the Nine Hole Pegboard Test had to be slower than that of the mean minus 2 SD of a healthy control group (mean peg/s 0.68, SD 0.14) [27]. Patients were assigned pseudo-randomly by the occupational therapists not involved in the study to two groups receiving either conventional treatment only (n = 20, henceforth CG), or music-supported training in addition to conventional therapy (n = 20, henceforth MG) according to the following constraints: (1) equal number of patients in CG and MG, (2) an equal number of left- and right-affected participants in each group. Table 1 shows pertinent clinical and demographical data without any significant differences between MG and CG patients. The majority of left-hemisphere patients (n = 6 in each group) showed an aphasia of differing syndromatology (Broca and Wernicke) and severity (mild to moderate). All of these patients were able to understand the instructions during assessments and training, and had been tested before with the Aachener Aphasie Test (AAT) to determine speech capabilities. Five additional potential participants were excluded, because severe perceptual or cognitive deficits revealed by neuropsychological testing did not allow their participation. None of the remaining patients had been diagnosed with depression or other psychiatric or neurological diseases. They were all native German speakers. All of the 40 patients enrolled in the study completed the whole training and assessment program. There were no drop outs.

Table 1 Relevant clinical and socio-demographic parameters of MG and CG patients

	MG	CG
Affected extremity left/right	10/10	10/10
Sex (F/M)	8/12	5/15
Age Mean (SD)	58.1 (9.9)	54.5 (10.2)
School education in years	9.8	9.3
Handedness right/left/ambidex.	18/1/1	18/1/1
Ischemia/Haemorrhage	16/4	18/2
Months after onset of disease	2.1	1.9
Barthel Index Mean (SD)	80.0 (18.6)	82.7 (17.2)

Informed consent was obtained from each subject after they received a detailed explanation of the nature of the study. The study was approved by the ethics review board of the University Hospital of Magdeburg.

Evaluation of motor functions

Motor functions were assessed prior to and after the treatment for CG and MG using the following instruments:

(1) Computerized movement analysis

A computerized movement analysis system (CMS 50, Zebris, Isny, Germany) was used based on the continuous recording of ultrasound impulses from senders applied to the dorsal phalanges of the index finger between the distal and proximal interdigital joints (DIP and PIP), over the metacarpophalangeal (MCP) joint and over the dorsum of the wrist joint. Sampling rate was set at 200 Hz, resulting in a temporal resolution of 66 Hz per sender. Continuous calculation of the 3D-positions of the three senders was done with commercially obtainable software (WinData 2.19.3x, Fa. Zebris). For details of movement registration and position of senders see Hermsdörfer et al. [28, 29].

In brief, two self-paced diadochokinetic movements of the upper limb were tested on each hand: whole hand tapping and index finger tapping. Patients were instructed to move as fast as possible without an external pace-maker. The importance of movement speed was stressed when giving the instructions. Data analysis (software "3DA-Version 1.5", © C. Mar-quardt, Munich, Germany) was performed on five movement cycles yielding the following measures for each task:

(a) Frequency (FREQ): number of full cycles/second.

(b) Number of inversions of velocity profiles (NIV) per movement segment. This is an established measure of the "smoothness" of the movements. Inversions with amplitudes less than 3% of maximal velocity were excluded. The best value that could be reached was 1.

(c) Average maximum angular velocity (VMAX) in °/second.

As suggested by Hermsdörfer et al. [28, 29] we omitted the first and the last movement cycles to exclude artefacts due to movement onset/offset or fatigue. The five selected movement cycles were determined by marking the movement onset of the second and the offset of the sixth cycle. Three such measurements were conducted per task. In a second step a segment analysis was made for the selected movement cycles. Data was averaged over the five cycles and three repetition to yield the measurement for the individual subjects, which were entered into the statistical analysis.

Table 2 Results of the pre-testing of motor functions between groups (Mean, SD)

Motor test/Parameter	MG	CG	F(1,38)
FREQ Finger tapping	2.2 (1.8)	1.8 (1.6)	0.58, n.s.
VMAX Finger tapping	171.1 (125)	133.9 (112.5)	1.00, n.s.
NIV Finger tapping	2.4 (1.6)	2.5 (1.6)	0.26, n.s.
FREQ Hand tapping	1.8 (1.6)	1.6 (1.4)	0.20, n.s.
VMAX Hand tapping	92.7 (75.7)	103.1 (110.7)	0.12, n.s.
NIV Hand tapping	2.5 (1.5)	2.7 (1.4)	0.81, n.s.
ARAT	36.9 (22)	32.8 (24.2)	0.32, n.s.
Arm Paresis Score	5.3 (2.3)	4.4 (2.9)	1.19, n.s.
BBT	25 (15.7)	27.6 (21.3)	0.19, n.s.
9HPT	4.9 (4.3)	4.2 (4.4)	0.26, n.s.

n.s. = non-significant

(2) Action Research Arm Test – ARAT [30, 31].
This test assesses pertinent functions of the upper extremities within four subtests: grasp, grip, pinch, and gross movement, each containing items arranged in hierarchical order or difficulty. The maximum possible score is 57.

(3) Arm Paresis Score [32].
This arm function test consists of seven simple tasks for the affected hand alone and both hands together (opening of a jar of jam, drawing a line, picking up and releasing a 2″ and 0.5″ cylinder, drinking water from a glass, combing ones hair and opening/closing a clothes peg). For each successful task, a score of 1 is given.

(4) Box and Block Test - BBT [33].
This test, consisting of a box with 2 compartments and 150 cubes, measures gross manual dexterity. The subject has to grasp one cube at a time and move it from one compartment to the other. The number of cubes transported within one minute is scored for the paretic and healthy extremity.

(5) Nine Hole Pegboard Test – 9HPT [34]
Patients are asked to pick up nine rods (32 mm long, 9 mm diameter) and place them into holes of 10 mm diameter as fast as possible. The time needed for placing all nine rods is transformed to a point-score, which was used in subsequent statistical analysis (10 points for 5–15 seconds, 9 points for 15 and 25 seconds etc.) Zero points were given if the task could not be performed. We developed this score system based on our observations with pilot patients to accommodate the data of those few patients who needed an exceedingly long time for the task (or even failed to perform) during the pre-test.
There were no significant differences in pre-testing of motor functions between groups (see Table 2 for details).

Conventional therapy

All participants, CG and MG, received standard therapies according to the instructions of the attending neurologists including individual physical therapy, individual occupational therapy using different materials and group therapies, each 30 minutes in duration. MG patients received 27.4 units and CG patients 27.2 of conventional therapies within the 3-week study period (duration of each unit 30 minutes; see Table 3 for details).

Music-supported training

For 3 weeks, MG participants received 15 sessions, 30 minutes in duration, administered individually, in addition to conventional treatment. The CG patients only received conventional therapy.

Table 3 Number of conventional therapies (group mean) for the affected upper extremity within the 3-week study period (30 minutes per unit)

	MG	CG
Physical therapy *individual*	4.20	4.75
Occupational therapy *individual*	7.20	7.18
Fine motor activity *group*	8.30	8.17
Arm *group* (perception, function, coordination)	7.74	7.10
Total	27.44	27.20

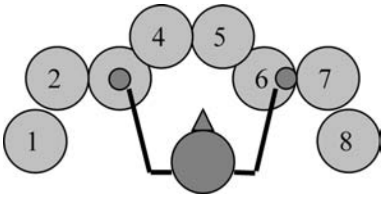

Fig. 1 Illustration of the set-up. Eight drum pads, four for each arm, were placed in a semi circle, all within reach of the patient

Two different input devices were used, a MIDI-piano and an electronic drum set consisting of 8 pads, each with a 20 cm diameter, arranged in front of the patient. The drum pads (designated by numbers 1–8) were used to produce piano (G, A, B, C, D, E, F, G‘) rather than drum sounds. Similarly, the MIDI-piano was arranged in such a way that only 8 white keys (G, A, B, C, D, E, F, G‘) could be played by the subject. This offers the advantage of an input device testing fine motor skills (piano) and another input instrument testing gross motor skills (drum set), while keeping the output constant. The different modules are described and the rules for progression from one level of difficulty to the next are described below. The training was applied and monitored by the first author. Each session was documented and recorded for later analysis.

From experience gathered in a number of pilot patients, a modular training regime with stepwise increase of complexity was designed.

Because of the different impairment patterns, some patients received training exclusively on the drum pads (n = 3) or the piano (n = 12), while others were treated using both instruments (n = 5, 15 minutes per instrument each session).

For drum training, patients were seated on a chair without armrests or in their own wheelchair in front of the 8 drum pads (Fig. 1). The height and proximity of the drum pads were individually adjustable, because at the beginning of the experiment, only some of the participants were able to hit the drums with their extended arm, and some could only reach the lower drum pads (1–3–6–8). Each exercise was first played by the instructor (S.S.) and was subsequently repeated by the patient. The instructor stood behind the patient and supported the affected extremity if necessary.

Similarly, patients were seated in front of the MIDI-piano with the instructor sitting next to them or standing behind them (on the affected side). Again, an exercise was first demonstrated by the instructor and then repeated by the patient. Patients started with the affected upper extremity and then played with the affected and healthy hand together.

The training was adaptable to the needs of the patients, in terms of the number of tones they were required to play, velocity, order, and limb used for playing. Furthermore, the degree of difficulty was systematically increased using 10 set levels. Every patient started the exercises (between 8 and 12 per session) at the lowest level by playing (hitting) single tones or the same tone on the same drum pad or key. If patients successfully managed this task, they continued on the next level, if not, the previous task was repeated.

In the subsequent levels, patients were required to use an increasing number of drum pads (or piano keys) until all eight tones could be played in varied sequences. The most difficult levels required patients to play the beginnings of children's or folk songs and finally songs consisting of 5–8 tones with the paretic hand. Twenty different songs were available for the eight tones (e.g., Ode to Joy).

Frequent repetitions of identical movements, which have been proven essential for motor learning, were required. For further information on the training procedure, please contact the first author directly.

The measures derived from the motor test battery (computerized movement analysis, Action Research Arm Test, Arm Paresis Score, Box and Block Test, Nine Hole Pegboard Test) were used to assess the effect of the music-supported training and constituted the dependent variables. These were entered into an ANOVA design with group (MG vs. CG) as between subjects factor and time-point (pre vs. post) as within subjects factor. Group × time-point interaction effects were taken as evidence of differential effects of therapy in the two groups. Moreover, to determine the size of the treatment effects Cohen's d [35] was computed for each group separately.

Results

The results for the *computerized movement analysis* are illustrated in Fig. 2. For *finger tapping*, MG but not CG showed an improvement for tapping frequency from the first to the second session (FREQ), which was reflected by an interaction of group × time-point (F(1,38) = 35.97, p < .001). Improvements restricted to the MG were also found for the parameters inversions of velocity (NIV) (group × time-point; F(1,38) = 12.42, p = .001) and maximal angular velocity (VMAX; F(1,38) = 4.93, p = .032).

With regard to *hand tapping*, a similar pattern emerged with improvements seen in the MG but not in the CG patients. This was reflected by group × time-point interaction effects for the parameters frequency (F(1,38) = 34.80, p < .001), NIV (F(1,38) = 11.52, p = .002) and VMAX (F(1,38) = 4.52, p = .04).

The results for the *Action Research Arm Test*, *Arm Paresis Score*, *Box and Block Test* and *Nine Hole Pegboard Test* are summarized in Table 4. The MG patients showed a substantial improvement over time compared to the CG patients in the Action Research Arm Test (group by time-point interaction; F(1,38) = 13.94, p < .001). A similar pattern emerged for the Arm Paresis Score (group by time-point interaction; F(1,38) = 6.66, p = .014), the Box and Block Test (group by time-point interaction, F(1,38) = 49.80, p < .001), and the Nine Hole Pegboard Test (group by time-point interaction, F(1,38) = 4.78, p = .035) (Table 5).

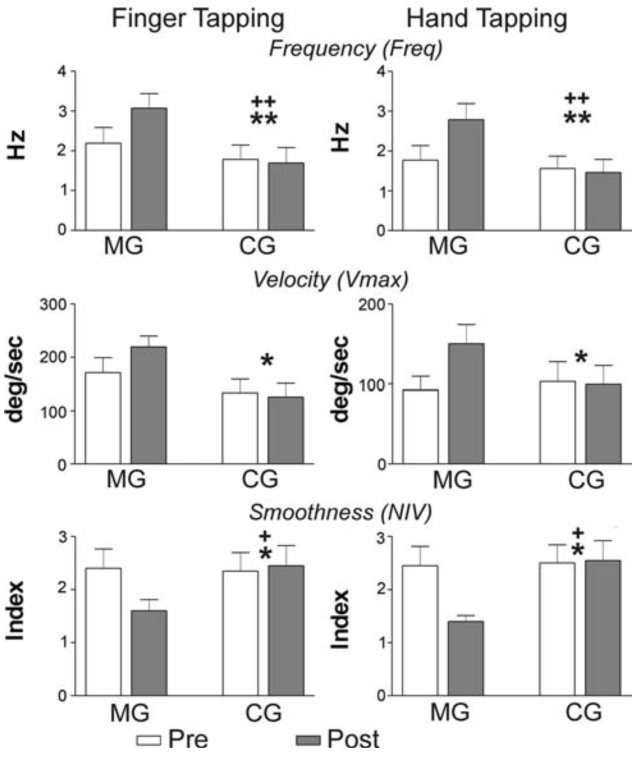

Fig. 2 The results of index finger tapping and hand tapping measured with the computerized movement analysis system demonstrated significant improvement after training in the MG (+ is intragroup p value < .05; ++ is intragroup p value < .001; * is intergroup p value < .05; ** is intergroup p value < .001)

Effect sizes were determined using Cohen's d [35]. In the literature, effect sizes of 0.2 are considered small, effect sizes of 0.4–0.6 moderate and effect sizes of 0.8 large. Effect sizes for MG patients for the NIV finger tapping, NIV hand tapping and Box and Block Test, were large. For the FREQ finger tapping, VMAX finger tapping, FREQ hand tapping, VMAX hand tapping, Action Research Arm Test and Arm Paresis Score effect sizes must be considered moderate and for Nine Hole Pegboard Test small. For the CG, all effect sizes were extremely small.

To assess subjective aspects of the music-supported training, patients from the MG were asked to rate on a 5 point scale to what extent they benefited from the training ("optimal", "high", "medium", "some" or "none"). With regard to generalization of the training effect to every-day functions, 85% of the participants reported an optimal to high degree of transfer, while 15% rated their outcome in the middle range. Because participants were asked to assess specifically their subjective impression regarding the music-supported training, this measure was only obtained in MG patients.

Discussion

The present study has demonstrated that patients suffering from incomplete paresis of an upper

Table 4 Results of the motor tests (Mean, SD)

Motor Tests	MG		CG	
	Pre	Post	Pre	Post
ARAT**	36.9 (22)	45.7 (14.2)	32.8 (24.2)	33.3 (24.3)
Arm Paresis Score*	5.3 (2.3)	6.5 (0.7)	4.4 (2.9)	4.5 (2.9)
BBT**	25 (15.7)	39.3 (16.4)	27.6 (21.3)	28.9 (21.5)
9HPT*	4.9 (4.3)	6.1 (3.7)	4.15 (4.4)	4.3 (4.2)

Group by time-point interaction **p < .001, *p < .05

Table 5 Results of the ANOVA and mean effect sizes for dependent measures

	Time-point (Pre/Post) F(1,38)	Group × Time-point F(1,38)	MG Cohen's d	CG Cohen's d
FREQ Finger tapping	23.70**	35.97**	0.52	0.05
NIV Finger tapping	5.92*	12.42*	0.79	0.12
VMAX Finger tapping	2.59	4.93*	0.45	0.07
FREQ Hand tapping	23.45**	34.80**	0.59	0.07
NIV Hand tapping	7.75*	11.52*	0.80	0.07
VMAX Hand tapping	3.52	4.52*	0.62	0.03
ARAT	17.93**	13.94*	0.47	0.02
Arm Paresis Score	9.31*	6.66*	0.70	0.04
BBT	70.80**	49.80**	0.89	0.06
9HPT	7.73*	4.78*	0.31	0.04

**p < .001, *p < .05

extremity clearly benefited from 15 sessions of music-supported training in addition to conventional therapies in a neurological rehabilitation hospital.

MG but not CG patients showed clear improvements regarding the range of possible movements (Action Research Arm Test, Arm Paresis Score), the speed of movement (Box and Block Test, Nine Hole Pegboard Test, parameter frequency and velocity derived from computerized movement analysis) and the quality of movement (e.g., parameter NIV). Of significance is the fact that the test battery included measures with high ecological validity (e.g., Box and Block Test), and thus a generalization of treatment benefits for real-world situations is highly likely. Moreover, ratings by the patients revealed a high subjective benefit of the training program.

The question then arises, what mechanisms might be involved in bringing about the dramatic benefits in the MG patients.

Music-supported training – a variant of massed practice regimes?

One feature of the current training program was the intensive and repetitive practice of movements using the piano or drum set for 15 sessions over a period of 3 weeks. The question therefore arises whether the benefits seen in the current study are due to the specific aspects of the treatment, i.e., the use of musical instruments, or simply the results of intensive practice. As the most frequently used motor rehabilitation method involving massed practice, constraint-induced movement therapy (CIMT) is based on motor restriction of the unaffected upper extremity using a resting hand splint and sling and training of the affected extremity. The most effective CIMT factor appears to be prompting patients to repeatedly practice the use of the paretic arm for several hours per day over a period of consecutive days [36, 37].

Typically, CIMT consists of two main elements: (1) restriction of movement of the unaffected upper extremity by placing it in a resting hand splint/sling construction for 90% of the time spent awake for a period of 10–20 days and (2) training of the affected arm using a procedure termed "shaping" (i.e., execution of a set of motor tasks) for approximately 6 hours/day on the weekdays during the therapy period. According to a recent meta-analysis of van Peppen, the increase in dexterity amounted to an effect size of 0.46 of the paretic arm after CIMT [38]. Concerning everyday activities (ADL), an effect size of 0.23 was found. Van der Lee compared three CIMT studies and found small to moderate effect sizes on dexterity, i.e., between 0.34 and 0.45, and no effects on ADL (0.18) [4]. While the training in the current study amounted to "only" 15 sessions of 30 minutes duration and thus was considerably less time-intensive than typical CIMT programs it nevertheless produced effect sizes of up to 0.9. This suggests that in addition to the intensity aspect other factors might be instrumental for the effectiveness of music-supported training.

The role of auditory feedback?

A striking feature of the current data set is the improvement of movement quality as indicated by a decrease in the parameter NIV derived from the computerized movement test (Zebris) and the increase in tapping frequency. A likely reason for this improvement, which should translate into better performance of fine motor tasks in real life, is the immediate auditory feedback entailed in MT. That is, for each movement the patient gets information as to how well she or he is executing the template tone sequence or melody.

Strokes are known to lead to an impairment of proprioceptive feedback information, and it has been suggested that proprioceptive reafferences play an important role in updating the internal representations during movement [39–41]. Also, data from recent experiments by Dancause et al. suggest that movement errors committed by moderately to severely hemiparetic patients were due to impaired interpretation of proprioceptive information concerning limb position [42]. Therefore, auditory feedback, as used in the present study, may serve to counteract this deficit, while standard occupational and physiotherapies either use unspecific sensory stimulation that do not require focussed attention or discriminative effort or provide only global feedback as to whether or not a movement is achieved [5]. In order to assess the role of auditory feedback, movements could be trained using muted piano or drum set in a further study.

Audio-motor integration?

A number of recent studies have pointed out that practice on a musical instrument leads to “audio-motor integration”. For example, Bangert and Altenmüller required piano-novices to practice simple melodies on a piano for 5 weeks (25 sessions of 20 minutes) [24]. They mapped DC-EEG-potentials at several points in time when patients were either listening to the melodies they practiced or playing them on a muted keyboard. Remarkably, the scalp maps of these conditions were exceptionally similar after practice, pointing to activation of auditory brain areas during silent piano playing and motor areas during listening (see also, Bangert et al. for a related fMRI study) [25]. These changes were interpreted as neural correlates of audio-motor integration. There are certain similarities between the training modalities used by Bangert and Altenmüller and the current music-supported training [24]. We would like to point out, however, that pre- and post-testing of motor functions in the current study was carried out in tasks *not* involving the musical instruments. Thus, while audio-motor integration might have helped patients to improve during practice, these improvements were clearly generalized to other situations.

Other factors

In addition to the ones discussed above, other factors might have contributed to the success of the training program. From the patients’ informal descriptions of their experience with the training it appears that this was highly enjoyable and a highlight of their rehabilitation process. Most patients appeared to be highly motivated throughout the 15 sessions. Motivation was maintained through the gradual increase of difficulty level over the different sessions allowing the patient to experience success and to receive positive reinforcement throughout the training.

Conventional therapy

It may seem odd that the control group, who received 27 units of conventional treatment on average (see Table 2), did not show improvement in any of the measures. This null effect is corroborated by previous observations, however [1–5]. Lincoln and Leadbitter investigated the influence of an enhanced physiotherapeutic program derived from the Bobath concept on arm function and on the degree of independence in activities of daily life (ADL) [2]. They found no differences regarding the time course of recovery and the functional outcome as a function of the kind of treatment program (regular vs. enhanced) or as a function of therapist (experienced vs. trainee). Moreover, Lincoln and colleagues demonstrated that increasing the intensity of a Bobath derived therapy did not improve the recovery of arm function in stroke patients (see also Parry) [3, 43]. Likewise, Langhammer and Stanghelle found Bobath therapy to be less efficient than a task specific motor relearning program with respect to motor recovery and the improvement of ADL in the rehabilitation of stroke patients [14]. Thus, the current study is not unique in casting doubt on the effectiveness of conventional therapies in the remediation of motor deficits after stroke.

Open questions

Given the marked improvement of patients in the MT group, it is of interest to compare the degree and speed of improvement, the generalization of training effects and the acceptance by the patients observed in MT with other new treatment modalities. We have thus initiated a follow-up study comparing a group of patients receiving MT with a group receiving constraint-induced movement therapy. Furthermore, it is probable that motivational factors, for instance the positive experience to learn a new "cultural skill" after a traumatic event such as having a stroke, may play a role. These factors will be controlled in the follow-up study comparing different training strategies.

An obvious next step concerns the neural correlates of improvement induced by MT. With regard to CIMT, a number of measures have been used. Using transcranial magnetic stimulation Liepert et al. found a training-induced increase of the cortical area that yielded motor responses of the abductor pollicis brevis muscle, suggesting changes in the excitability of motor cortex and recruitment of more neurons [8, 9]. The increase of the readiness potential for voluntary movements after CIMT has been interpreted in a similar fashion. Also, using PET, a decrease of atypical bilateral activation of the primary sensorimotor cortex of movements with the affected limbs was found after CIMT [10, 11]. These findings were corroborated by recent fMRI measurements [44–46]. In a follow-up study, we will therefore employ TMS, EEG-derived measures and functional neuroimaging to pinpoint the neural changes underlying the improvements made by MT.

Limitations of the current approach

While the current study provides first data on the effectiveness of music-supported training and on its feasibility in a clinical routine setting, the current study clearly has some limitations. While the improvement on several of the tests included in the test battery attests to the generalization of training effects, the stability of the improvements needs to be assessed in further studies. Also, the length and number of the training sessions (15) is a further critical variable that might be manipulated in future research. The length of a session in the current study was clearly below that usually used in studies of constraint-induced therapy. It is unclear at present, whether an increased dose might increase effect sizes. A further problem of the current study pertains to the different overall dose in therapy in the MG and CG groups. While both groups received 27 units of conventional therapy, the MG group had been exposed to an additional 15 units of music-supported training. As there was no tendency of improvement in the motor test battery in the CG, we do not believe that the marked improvement in the MG can be attributed to a simple dose effect.

A more general limitation of our training approach, which it shares, however, with constraint-induced therapy, is its limited applicability in severely compromised patients. While strict inclusion/exclusion criteria are important for clinical studies, our approach might be adapted to more severely impaired patients in clinical settings in the future, e.g., by using different instruments or custom made devices emitting MIDI-triggers.

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