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Sonification-based Exercise as an Add-on Therapy for Upper Limb Motor Recovery in the Acute Phase of Stroke

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Abstract

Music- and sonification-assisted rehabilitation is being increasingly investigated in motor recovery after stroke, but only few studies have thus far involved patients in the acute phase of the disease.

In this quasi-experimental study (no randomization has been applied), patients with motor deficit of the upper limb fulfilling predefined inclusion criteria were sequentially enrolled onto a program of sonification-based exercises through a serious game, id est. an adapted piano-keyboard as an add-on to standard rehabilitation treatment. Based on the potential efficacy of the auditory-motor networks, the aim was to further stimulate the patient on tactile stimulation, limb lifting and finger motor individualization. Starting 2 to 7 days after stroke onset and for an overall 21-day duration, the experiences were performed in the hospital. After the enrollment of 13 patients as experimental group, 12 more patients were enrolled as control group and underwent standard physiotherapy treatment.

For all patients, the Action Research Arm Test (ARAT) was administered at T0 (prior to therapy), T1 (after 10 days) and T2 (end of treatment) while the quality of life, as assessed by the SF-36 scale, was evaluated at T0 and T2.

For the ARAT, statistical analyses were performed by Student's T test for paired and unpaired samples, respectively. In both groups, ARAT scores significantly improved from T0 to T1, but the sole experimental group displayed a significant motor improvement from T1 to T2.

Again, only in the case of the experimental group quality of life showed a significant improvement in the perception of physical health.

Overall, add-on treatment with sonification exercises was feasible in the acute phase of stroke, leading to recovery which tended to be more lasting than in the control group. Motor recovery of upper limb function paralleled an improvement in the perception of physical health.

These results are the basis for a future randomized controlled study on the effect of sonification add-on therapy in the acute phase of stroke.

Keywords: Stroke • Rehabilitation • Upper limb • Acute phase • Sonification-based exercises • Music

Introduction

Stroke is the third cause of mortality in developed countries and the second cause of disability worldwide [1,2]. Advances in primary and secondary prevention of stroke have led to a reduction of incident cases by means of the modification of life habits, while pharmacological therapies and improvements in recanalization in the hyperacute phase of ischaemic stroke have led to a better short- and medium-term outcome. On the other hand, incidence reduction is not fully counterbalanced by the raising risk due to the increasing life expectancy and-despite improvements in the acute phase of stroke care; still one third of patients suffering a stroke present persistent disability and handicap [3].

Stroke survivors with disability also present impaired quality of life; they frequently depend on assistance by caregivers of institutional facilities, with motor impairment playing a highly significant impact [4].

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The rehabilitation approaches dedicated to stroke generally focus on the plasticity of the residual non-affected brain tissue, in order to achieve variable degrees of functional recovery. Among such techniques, an increasing attention is dedicated to technology-assisted schedules, including models of virtual reality and augmented reality. Aiming to give a further contribution, the use of music as an effective stimulus for recovery of neurological functions in neurological diseases, is becoming increasingly interesting also in cases of stroke [5,6]. A good base for this comes from the growing well-documented links between the auditory and the motor systems and by the implication in these processes of emotion and reward networks [7]. Music as a rule stimulates motion and is a strongly activating factor, involving physiological and emotional aspects.

Music may exert a favourable impact in functional recovery in stroke, both when delivered passively and even more when individually produced through active movements. This latter approach is known as sonification and it implies the motion capture of the patient's gestures and the immediate translation of such movements into the sounds of auditory feedback.

So far, essays of sonification-assisted rehabilitation in stroke have mostly targeted patients in the sub-acute and chronic phase of stroke [8,9].

In this study focusing on the rehabilitation of upper limb strength deficit in the acute phase of stroke, a sonification-based approach, has taken place through exercises producing sounds *via* a musical keyboard and visual-auditory feedback as an add-on treatment to standard rehabilitation provided in our Institution.

The results obtained in the group of patients receiving such treatment (experimental group) were compared to those of a group of patients with similar clinical features treated with standard of care (control group).

Materials and Methods

The essential aim of the study was to verify the feasibility and potential effectiveness of a sonification approach added to standard physical therapy in patients in the acute phase of a stroke having caused upper limb deficit. Due to the temporal constraints of the Interreg project, a compromise was chosen in regard of the protocol: The study began with the experimental group and at 3/4ths of it the control group started up. Such a solution led to a quasi-experimental study since the distribution of the population was not correctly randomized.

The project was approved by the Ethical Committee Brianza.

Population

Two groups of patients were sequentially enrolled, provided they fulfilled inclusion and exclusion criteria and treated with standard physical therapy plus sonification (group A) and only standard physical therapy (group B).

The following inclusion and exclusion criteria were adopted.

Inclusion criteria

- Patients with upper limb paresis due to either ischaemic or haemorrhagic stroke;
- Stroke onset at least 48 hours and less than 7 days;
- Lack of significant impairment in comprehension;
- ARAT scale score equal to or higher than 3.

Exclusion criteria

- Age younger than 18;
- Concomitant medical or psychiatric conditions likely to interfere with adherence to the treatment protocol.

Methods

The standard of care in physical therapy of acute stroke patients in our Center includes early management (with beginning of therapy within 24-72 hours after stroke onset) with daily sessions of 45' per day in weekdays during hospitalization in Stroke Unit and in the Neurology Unit, increasing to 45' × 2 per day after transfer of the patient to the intensive rehabilitation Unit (Bellano Hospital, ASST Lecco), with an overall duration of approximately 21 sessions during the stay in intensive rehabilitation facility.

The experimental group (standard of care plus the sonification approach) underwent 30 minute sessions after every standard treatment, during which the patients were trained to a performative musical experience *via* the use of a traditional piano keyboard equipped with an ad hoc software developed for this study.

Patients were evaluated at the following time points both by the physiatrist and by the neuropsychologist: time 0 (T0), just prior to the beginning of rehabilitation, time 1 (T1), on day 10 of the treatment, time 2 (T2), at the end of the 21-session training program.

The primary endpoint of the study is given by an improvement of at least 7 points at the ARAT scale score in patients undergoing the experimental treatment in comparison with those undergoing the standard physical therapy. The motor skills of the upper limb were assessed through the ARAT test in T0, T1 and T2 [10].

A secondary endpoint has been obtained through the SF-36 survey administered in order to evaluate the quality of life at T0 and T2 [11].

Setting

The patient is in a sitting position, on an armchair. A portable musical keyboard-with normal-size keys and with a 2-musical octaves extension- is connected to the chair and held in the right position *via* a jointed arm. For ergonomic purposes, the keyboard is fixed in an oblique position and may be regulated by the physiotherapist. The musical instrument is endowed with slight touch pad in its low left end and with potentiometers in its upper right end.

Facing the patient, a laptop computer is placed on a table. Through it an ad hoc developed multimedia application is used in order to administer the exercises, to record the performances of the subject and to deliver the related auditory feedback (sonification) (Figure 1).

The musical keyboard is connected to the laptop *via* a traditional USB cable. During the treatment neither the keyboard nor the computer are connected to the electric power system.

Musical exercises

The program delivers exercises of increasing complexity, based on three distinct approaches:

- Tactile stimulation (the patient puts his/her hand on the keyboard sliding on it);
- Gross motor stimulation (consisting in limb raising);
- Fine motor stimulation (individualization of finger gestures).

Each exercise is introduced by a screen where different parameters- such as the music track, the speed- may be modified by the physiotherapist depending on the subject's capabilities.

For each exercise the patient is given different tasks based on listening/perception and production.

In general the exercises are developed according to difficulty levels:

- Digitally non-individualized key pressure, with stimulation for the activation of wrist flexion and shoulder adduction;
- Repeated pressure on single keys, or rhythmic exercises finalized to the control of wrist and shoulder;
- Pressure on distinct keys in a sequence, id est. melodic exercises finalized to a stimulus for finger individualization;

Figure 1. An example of the experimental setting.

- Shifts in heights, volumes and rhythms through the manipulation of potentiometers, with stimuli finalized to pinch, finger individualization and flexion of metacarpal-phalangeal and interphalangeal joints.

Statistical analysis

In order to assess putative differences prior the planned interventions, the scores in the ARAT test of both the experimental and control group were compared at T0. Then within each group data were compared between T0 and T1 and between T1 and T2.

Student's T-test was used for the comparisons, with p significance set at 0.05.

Results

Overall, 25 patients were enrolled in the study: 12 participated to the experimental group treated according to the standard of care plus sonification while 13 participated to the control group treated according to the only standard of care. One patient in the experimental group dropped out after T1 assessment due to wish of early dismissal from the intensive rehabilitation unit (number 4 in Table 1).

Epidemiological data, stroke type and ARAT score in t0 of both the groups are reported in Table 1. Of note, there was preponderance of male sex and of ischaemic *vs.* haemorrhagic stroke, but both these features were equally represented in the 2 groups. Mean age of the experimental group was lower (67.7 *vs.* 77.2), as well as median age (74 *vs.* 78), although the difference was not statistically significant.

Mean ARAT score at T0 was 28.9 in patients undergoing sonification add-on therapy *vs.* 34.6 in those delivered standard of care (p n.s by T-test). Treatment was started within a mean of 4 days from stroke in both groups.

When shifts in ARAT score were analyzed over time in the 2 groups (see Figure 2), both displayed a significant improvement from T0 to T1 (exp.group: p 0.002; ctrl.group: p 0.017), but from T1 to T2 only those delivered add-on sonification displayed a further significant improvement in the score (exp. group: p 0.015; ctrl. group: N.S.) (Figure 2).

This was reflected in a similar mean ARAT score at T2 in the group of controls and add-on treatment, with values of 47.9 and 47.8 respectively.

Results of SF-36 quality of life testing are reported in Figure 3.

In patients undergoing add-on sonification therapy, the expected decrease in the score for physical health from T0 to T2 was much less marked than encountered in the group undergoing standard physiotherapy ($p<0.05$ Student's T-test).

Discussion

According to the literature, the effectiveness of the use of music in motor and cognitive impairments rehabilitation seems obvious, both after stroke and other neurological diseases. However tools and methods used are different one from the other [12,13].

The paucity of literature data on the sonification-assisted treatment in the acute phases of stroke, likely depends on a variety of factors, among which, possibly, the most relevant is the rapid and spontaneous changes in clinical deficit during the first days after stroke [14,15]. In our opinion another critical aspect derives from the difficulty in engaging patients in a seemingly ludic activity in the context of an often dramatic change in motor abilities and of on-going diagnostic and therapeutic work-up in a sub intensive care unit or, in the following days, of an acute neurology ward.

Despite the difficulties in the engagement of patients, those who started the add-on treatment mostly completed it. Starting the treatment in the first days after the neurological event allowed us to carry out all the experimentation during the hospitalization, avoiding drop-out.

Table 1. Sex, age, stroke type and ARAT baseline of the two groups, add-on sonification *vs.* standard of care.

	Sex	Age	Stroke type	ARAT t0
Experimental Group (add-on)	M	58	Ischaemic	40 rt
	M	75	Ischaemic	20 lt
	F	34	Ischaemic	33 rt
	M	75	Ischaemic	24 lt
	M	75	Ischaemic	25 rt
	M	72	Ischaemic	29 lt
	M	74	Ischaemic	13 lt
	M	74	Ischaemic	11 rt
	F	54	Haemorrhagic	19 lt
	M	78	Ischaemic	51 lt
	M	62	Ischaemic	44 rt
	F	82	Ischaemic	38 rt
Control Group (standard of care)	M	81	Ischaemic	08 rt
	M	79	Ischaemic	06 lt
	F	61	Ischaemic	51 lt
	M	75	Ischaemic	54 rt
	F	82	Ischaemic	42 rt
	M	84	Ischaemic	34 rt
	M	78	Ischaemic	35 lt
	M	78	Ischaemic	45 lt
	M	84	Ischaemic	08 rt
	M	73	Haemorrhagic	22 rt
	M	70	Ischaemic	47 lt
	M	81	Ischaemic	49 rt
	F	78	Ischaemic	50 rt

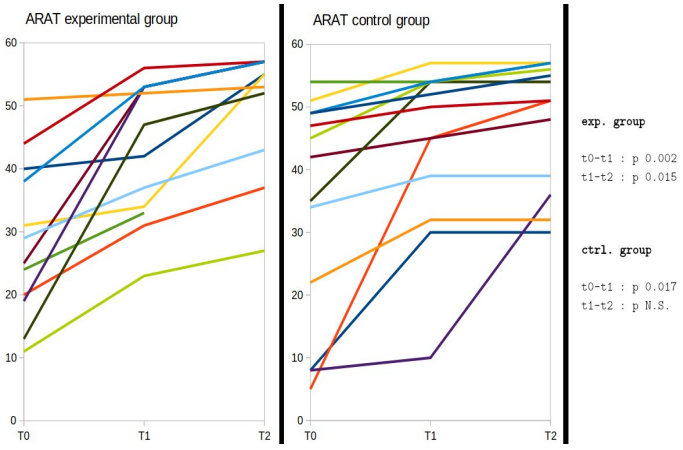

Figure 2. Graphical representation of the ARAT scores in t0, t1 and t2 of all the subjects of the two groups.

Moreover, patients in the experimental group did not seem to grasp the novelty in the approach proposed. They rather accepted it as part of the rehabilitation program.

Some minor differences were present between the 2 groups before the beginning of the treatment. Mean age was lower in the experimental add-on group and motor upper limb impairment was also more severe in this group, although neither difference with the control group reached statistical significance.

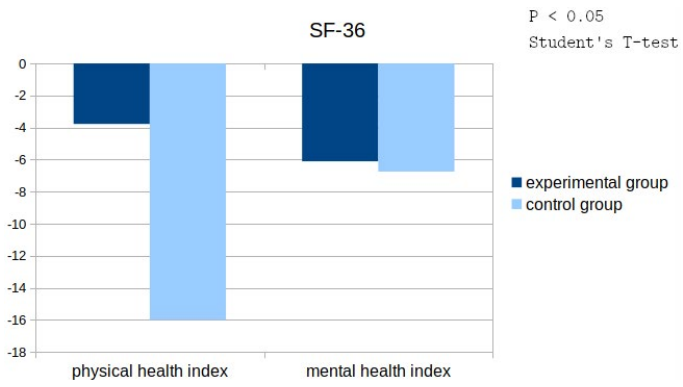

Figure 3. Results of SF-36 quality of life testing: t2 scores in physical and mental health in both subgroups as compared with t0 scores.

Compared to other studies, we engaged also patients with very serious motor impairment of the upper limb.

In both groups, an early significant motor recovery took place from T0 to T1. On the other hand, motor recovery continued from T1 to T2 at a significant level only in the experimental group, suggesting a possible positive effect of sonification at a later phase of the rehabilitation treatment pathway.

In the very early phase after a stroke, the patient faces multiple challenges, among which a totally new and unexpected reality, with difficulties in comprehension and coping with the context of on-going diagnostic and therapeutic work-up. In this situation, it is not surprising that it may be hard for the patient to fully understand the novelty of the proposed approach and comply with motivation in the required exercises. Moreover, the later stage of the rehabilitation process takes place in a different setting, id est a different hospital. In such an environment, it may be easier for the patient to focus on the proposed treatments. This might partly account for the later improvement, from T1 to T2, which was detected only in patients undergoing add-on sonification therapy. These same patients participated in the proposed activity without great enthusiasm, accepting and performing it as a required exercise without appreciating its innovation and added value. During the acute phase of hospitalization, patients are still in a state of awareness and acceptance of their new condition. The main desire that accompanies them in this initial phase is to regain the functions they have lost and their independence in daily activities. They are often not in a position to understand that performance, e.g. in dressing, can be improved through different exercises such as those performed on a piano keyboard.

The control of the paretic limb is still an unknown aspect. Regardless the severity of the deficit, patients must learn to manage a part of themselves that has dramatically changed in function. Frustration at this moment is difficult to handle. Moreover, being in the hospital makes it harder to appreciate the apparently recreational dimension of the sonification activity.

In a recent randomized trial two groups of sub-acute stroke patients were either treated with standard rehabilitation therapy or with standard therapy plus sonification [16]. The assessment of motor hand recovery was evaluated by the Fugl-Meyer scale, starting with treatments at a mean time of approximately 30 days from the stroke. The results were better in the group randomized to add-on sonification therapy, in line with our results. They put in evidence the persistence of a temporal window for the motor recovery. Such a phase of intervention may be successfully extended for several weeks- at least eight- after the stroke.

This is also suggested by the results of a systematic review and meta-analysis conducted by GHAI in 2018 and published in Frontiers in Neurology [17]. In their review, the authors collected 23 studies but only 2 of those, included patients in the sub-acute phase after stroke [18,19], i.e. having suffered the stroke a mean of 30 days or 7 weeks respectively before the onset of treatments, whereas all the other 21 studies included patients who had a stroke from months to several years before. Proposing the same activity to a patient who has overcome the acute phase and returned home takes on a different connotation. The patients, who have regained their daily life despite the consequences of an ictal event, have structured and redefined their autonomy. They view an alternative activity with a different interest, as it can enhance what they have already accepted as their actual level of autonomy. Furthermore, as it is evident from the number of stroke patients examined and the number of patients recruited for sonification, it can be confirmed that the upper limb often shows spontaneous and rapid recovery in the first few days following the event, or that it may be so compromised that it cannot even be tested with the ARAT scale. In the latter case, unfortunately, even over time, recovery remains difficult and incomplete. This partly justifies the scarcity of literature about movement sonification in the acute phase.

With regard to the serious game and the sonification, some critical issues related to the patient's visual capabilities have been identified, including visual acuity and the presence of visual field deficits, as well as the patient's reaction time. The program had fixed latency time between input and execution requests. However, especially in the acute phase, patients may need longer time and this latency prevents them from coordinating properly with the request and execution of the task. Sometime it leads to a sort of syncopation between the performed movement and the succeeding stimulus. In this regard, it could be useful to give the therapist assisting the patient the possibility to adjust in real-time the time or speed of the stimulus through a remote controller while the patient is performing the tasks. This would allow each subject to perform the exercises at her/his own pace.

Perception of quality of life

The patients who underwent the add-on experience based on sonification show a better perception of quality of life in terms of the motor subscales of the SF 36 scale, as if using the paretic limbs in playful activities improves the perception of their own abilities. This confirms how effective the experience of performing art could be, not only in motor performance but in cognition as well and, more broadly, in the patient perception of his/her quality of life. This data is even more significant, although seemingly contradictory, considering the lack of enthusiasm with which the activity was carried out. There is a concordance between the continuous improvement in ARAT scores in the experimental group and the perception of improved physical performance. However, this difference in score, as compared with the standard physiotherapy group, did not take place in the mental health scores, underlining dissociation between the 2 sub scores.

Putting together the results and the difficulties encountered in promoting to stroke patients the experimentation in the acute hospital setting, we can draw some conclusions and suggestions for future experiences.

Since decades the scientific literature underlines that music in general and the sonification of movements in particular are more than recreational experiences. Such evidence must be reflected in the clinical domain too.

On one hand a particular attention should be given to the motivation of the patients. Together with their families, they could and should understand the potential benefits of the sonification of movement in the rehabilitative context through explanatory videos, featuring testimonials and brief examples.

On the other hand, the same attention should be dedicated to the staff training. It is essential to keep professional caregivers up-to-date on recent developments in regard to the neuroscience of music and its clinical usefulness. It is also worthwhile to allocate specific space and time for sonification treatments as an add-on to standard treatment. This should involve nursing and support staff to ensure the proper execution of the treatments. Facilitating the patient's readiness by having them dressed and seated with the physiotherapist would optimize the sometimes-tight timeframe of the hospital day, divided into clinical instrumental examinations, therapies and clinical assessments [20-22].

Conclusion

Overall, this study showed the feasibility and the potential usefulness of an early approach with sonification therapy as add-on therapy to standard physiotherapy in acute stroke with upper limb deficit, adding data to already

available evidence in the context of sub-acute or chronic phase. Taking into account the effectiveness of early and also very early mobilization in physiotherapy trials dedicated to stroke, there's now the need to deepen the actual impact of this early approach on medium term recovery which needs to be addressed in future adequately powered randomized trials.

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Conflict of Interest

No conflict of interest.

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