

SPECIFYING RHYTHMIC AUDITORY STIMULATION FOR ROBOT-ASSISTED HAND FUNCTION TRAINING IN STROKE THERAPY

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ABSTRACT

Following a stroke 90% of all patients suffer from a loss of arm and hand function, whereby 30-40% of them never regain full functionality ever again. Robot-assisted hand function training (RT) intensifies and complements common ergo-therapeutic treatment effectively. Most of robotic rehabilitation devices are connected to multimedia-environments offering playful training to promote motivation. “Rhythmic Acoustic Stimulation” (RAS), an effective therapeutic technique for post-stroke-treatment, was never specified, applied nor evaluated for RT.

This paper suggests specified sound designs with rhythmic stimuli for RT that aim to enhance function and motivation. Four pilot experiments are described evaluating, if specified rhythmic stimulation designs applied during a fine motor task influence motivation and function in comparison to no stimulation.

As results of these experiments indicate that rhythmic stimulation designs may enhance function and motivation, they are discussed for further observations applied in RT with stroke-patients.

1. INTRODUCTION

We clap our hands to express enthusiasm, we knock at doors, we grasp and manipulate objects, work with tools and express with gestures to interact with our environment. Accordingly, a lack of fine motor skills is extremely limiting in day life. As 9 out of 10 stroke patients suffer from a paretic arm syndrome, and 3 out of 4 patients never regain their skills needed in day life again, it is very important to enhance training strategies [1].

Generally treatment gains most success with early-onset of highly intensive training throughout activating therapies in which movements are practiced repetitively and in a goal-directed manner [2]. Motivation during the treatment is considered as determinant of successful rehabilitation [3].

To complement conventional therapy, robotic technologies are applied. Robot-assisted hand function training (RT) is considered as promising especially for heavy exposures of the arm paresis syndrome [4]. Studies showed that RT provided additional to conventional therapy enhances

rehabilitation outcomes in arm function, arm strength and coordination [5,6]. Usually robotic devices are connected to a multimedia environment in which sound occurs as one part of the system [7]. So far effects of sound were never observed particularly with a focus on arm function and motivation.

None of robotic technologies were ever combined with “Rhythmic Acoustic Stimulation” (RAS). RAS is a therapeutic technique in which patients practice motor tasks like walking or arm movements while listening to a metronome or to rhythmical music [8]. Reviews on effectiveness of sound in motor training for stroke patients showed that RAS lead to significant better results in gait training for stroke and Parkinson patients than other therapeutic approaches, and enhanced arm function [9].

This paper introduces specified rhythmic stimulation designs for RT aiming to enhance motivation during training and to influence functional outcome. An overview on the role of sound in rehabilitation robotics, and research on sound and music in motor rehabilitation is given.

Four experiments (E1-4) on effects of RAS on fine motor tasks are presented. As RAS was never specified for RT, four different rhythmic stimulation designs are proposed. In a first step, three pilot-experiments (E1-3) were performed with healthy subjects to investigate functional and motivational effects of these four different rhythmic stimulation designs on motor function and motivation in comparison to no stimulation during the performance of the Nine Hole Peg Test (NHPT). The goal was to determine effective designs for further examinations with patients. Two designs showing strongest effects in E1-3 were applied in experiment 4 (E4) with patients in a second step. In E4 functional effects of the two strongest designs seen in E1-3 were assessed with patients suffering from an arm paresis syndrome during performance of the Box-and-Block-Test (BBT).

The overall aim was to investigate if RAS is an effective sound application for further arising technologies in the field of motor rehabilitation.



2. BACKGROUND

2.1. Sound in rehabilitation robotics

During RT patients may hear machine-own noise of the robot, music and game sounds as one part of the multimedia environment, and a therapist talking to them beside of that. In training with games, sound occurs particularly in manners of voice guiding tasks and commenting performance, with environmental sounds like chirping of birds or wind aiming to stimulate perceived realism within virtual scenarios, action-related sounds like object collisions, and background music.

These sounds may influence attention, motivation and function in either positive manners by rising motivation during practice, enhancing movement qualities, lowering perceived size of effort and deepen participation during performance of tasks. But they might also lead to negative effects like distraction, fear, stimulus satiation, stress, or superimposed patient-therapist interaction, if not designed properly.

2.2. Sound and music for motor rehabilitation

Sound and music were already applied within a range of rehabilitation techniques for neurological patients [10]. Research outcomes on effectiveness of sound or music in this context were reviewed to develop therapeutic meaningful and specified sonic design for RT:

Bradt et al. 2009 showed that most significant results of sound applications in motor rehabilitation were gained in gait- and arm training for patients suffering from Parkinson's disease and stroke where rhythmical music or a metronome was applied with a therapeutic technique called "Rhythmic Acoustic Stimulation" (RAS). Under stimulation with RAS, patients suffering from motor deficits, benefit from training with rhythmic cues, because an external time-keeper facilitates movement initiation and synchronization. Studies on RAS in gait training showed that significant improvements in motor qualities were reached in comparison to standard physiotherapeutic treatments [11]. A single group pilot study investigated effects of bilateral arm training with rhythmic auditory cueing (BATRAC) and showed that six weeks of BATRAC improves functional motor performance of the paretic upper extremity as well as isometric strength and range of motion [12]. Another pilot study observed effects of RAS on training for arm reaching tasks for patients suffering of an arm paresis. Results showed a significant decrease in compensatory trunk movement, an increase in shoulder flexion, and a slight increase in elbow extension. Movement timing and velocity significantly improved.

It was shown that real-time musical-feedback, provided adequately, influences motor functions in rehabilitation positive [13]: Rosati et al. (2013) performed a

review on the role of auditory feedback in robot-assisted movement training after stroke. The authors concluded that potential effects of auditory feedback applications may enhance user engagement, the development during the acute-phase, and home rehabilitation devices. They propose, that auditory feedback applications in rehabilitation technologies might promote learning of more complex motor tasks, and could improve skill needed for activities of daily living, if applied properly [14,15]. Fritz et al. (2013) carried out a study in which healthy subjects were training with fitness machines under three conditions: In condition one, training was performed without sound. In the second condition, participants trained with strongly rhythmical music, and in a third condition, training was performed with rhythmical music which was manipulated in real-time. Results showed that musical agency significantly lowered perceived exertion during exercising with sport machines [16].

Research in the field of neuro-musicology on music and emotion found that, if sound or music is provided in a pleasant manner it may promote motivation generally [17].

Dautenhahn (2007) lined out that if sound is provided in an adequate design, it potentially engages a positive attitude towards training with technical systems [18]. This in turn could influence training motivation generally.

To explore effects of specified sound design for RT, behavioral data on effects on recovery are needed. Concluding to research outcomes in the field of motor rehabilitation, the application of RAS in RT was concluded as most promising design that might promote function. Pleasant rhythmical music and musical real-time feedback in RT could potentially motivate patients.

3. METHODS

3.1. Objectives

To evaluate if specified rhythmic stimulation designs for RT influence function and motivation, three experiments (E1-3) were conducted to detect effects of four different designs with healthy subjects. Conditions in E1-3 differed in degree of difficulty to provide comparable conditions between healthy subjects and limitations caused by arm paresis (see Fig.1). The aim in E1-3 was to determine designs achieving strongest effects on function and motivation to suggest specified rhythmic stimulation designs for further investigations with patients.

In a fourth experiment (E4) strongest designs seen in E1-3 were tested with 9 patients suffering from arm paresis. The goal of E4 was to assess functional effects of two strong designs in comparison to no stimulation.

Results of E1-4 could inform future approaches exploring effectiveness of RAS applied in RT with patients.

3.2. Experiment 1-3

Test participants:

20 healthy subjects took part in E1-3. 11 participants were female, 9 were male. The age ranged from 23 to 34 years. The mean age was 27.15 years with a standard deviation of 3.85. 19 participants had previous experiences in playing a musical instrument. All participants were right handed.

Technical set-up:

In E1-3 the Nine Hole Peg Test (NHPT) [19], a validated clinical assessment tool for specification of finger dexterity (tip pinch) was performed.

In this test participants sit in front of a wooden block which is divided into two sides. One side has a big hole in which nine small pegs are placed, and the other side has nine small holes in which the nine pegs should be placed during the test (see Fig.1, E1: normal condition). The task is to grasp nine pegs, one after the other and with one hand only, and to place them into the nine small holes. As soon as they are all placed in the holes, the pegs have to be put back to the big hole. Test participants are advised to perform the task as fast as possible. If a peg falls beside of the wooden block, it should not be picked up. A dropped peg is counted as one mistake.

The amount of mistakes reflects performance quality (p). In this test, duration (t) and performance (p) to completion of the task reflect manipulative fine motor skills, especially the ability to execute the pinch grip. To assess motivational aspects, a self-evaluation questionnaire was added. Here participants were asked to rate their mood (m) via Visual-Analog-Scale (-10: +10) in relation to their initial mood after every single task.

In E1 normal conditions were given, whereby in E2 and E3 technical limitations were applied to simulate difficulties given for patients due to their arm paresis (see Fig. 1: E2, E3):

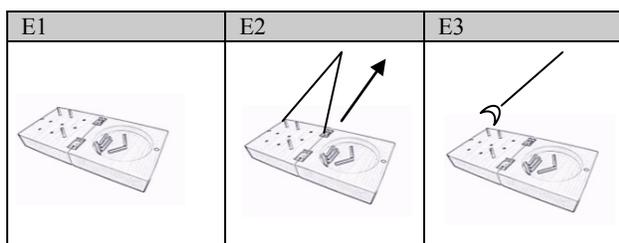


Figure 1: E1- normal condition, E2- limitation against elastic rope force backwards, E3- limitation by usage of mechanical grasp arm.

In E2 participants had to perform the test against force of elastic ropes pulling backwards. By this the muscles needed for arm- and finger extension had to work harder than in a normal condition.

In E3 participants had to use a mechanical grasp arm to perform the task. Like this a difficulty was achieved that should simulate a loss of precision that is given in arm paresis syndrome.

Procedure:

Before the start of the test, participants rated their initial mood via Visual Analogue Scale (-10:+10). All participants were informed about the test procedure via a pre-recorded audio guide. Before each experiment E1-3, participants were introduced to the task and the given condition by the audio guide again. Before data recordings started, one test trial was performed for each test condition (E1-3).

During the test performance throughout E1-3, four stimulation designs were provided via headphones and compared to a condition without stimulation:

- a) no stimulation
- b) metronome
- c) spearcon-beat: processed audio samples of words like “Super”, “Great” [20]
- d) waltz-music: “Voices of spring”, J. Strauss
- e) multisensorial beat: rhythmical hits on the foot and metronome

A tempo of 200 bpm was chosen to provide a speed up rate of 20% in relation to NHPT-time standard value table. The stimulation designs a-e were applied for each test of E1-E3 in a randomized order.

Duration till task completion (t) was measured with a digital stop watch up from first to last peg contact. Performance quality was assessed by counting the amount of mistakes. After each trial participants rated their mood (m) in relation to their initial mood via Visual Analogue Scale (-10:+10).

The paired t-test (level of significance: 0.1%) was performed for each experiment (E1-3), and of each variable (duration, performance, mood) to test if effects of different stimulation-designs were significant.

3.3. Experiment 4

Test participants:

In E4 9 stroke patients suffering from an arm paresis syndrome with heavy to middle exposure took part. 3 patients were female, 6 were male. The age ranged from 18 to 70 years, the mean age was 48.1 with a standard deviation of 17.81. 7 patients were right handed, 2 were left handed.

Technical set-up:

In E4 the Box and Block Test (B&BT), a validated clinical assessment tool for specification of manual dexterity (tip pinch) was performed [21]. In this test participants sit in front of a wooden box which is divided by wooden wall into two parts. In one part of the box 150 wooden blocks are placed. The task is to transport one block after the other from one side to the other side of the box. Within a time span of 60 seconds the task has to

be performed as fast as possible, with one hand only, and without throwing the blocks. The amount of blocks transported from one side to the other, reflect abilities of manual dexterity.

Procedure:

All patients were informed about the test procedure and were advised to perform the test with their affected side. The test was performed three times, whereby once without stimulation (a), and twice with rhythmic stimulation designs (b,d), that were displayed with headphones. The rhythmic stimulation designs were once a metronome-beat (b), and once waltz-music (d), both provided with a tempo of 200 bpm like in E1-3. The stimulation designs were applied in randomized order. A digital stop watch was started with first manual block contact. Blocks that were transported from one side to another within 60 seconds were counted.

A paired t-test (level of significance: 0.1%) was performed, to test if effects of different stimulation-designs were significant.

4. RESULTS

4.1. Experiment 1

E1: duration

In E1 duration was best with waltz-music (*mean time (d)=16.6s*), followed by spearcon-beat (*mean time (c)=16.8s*) and weakest without any stimulation (*mean time (a)=18.3s*). A standard deviation of 0.95 was given. Effects were not significant (see Fig. 2).

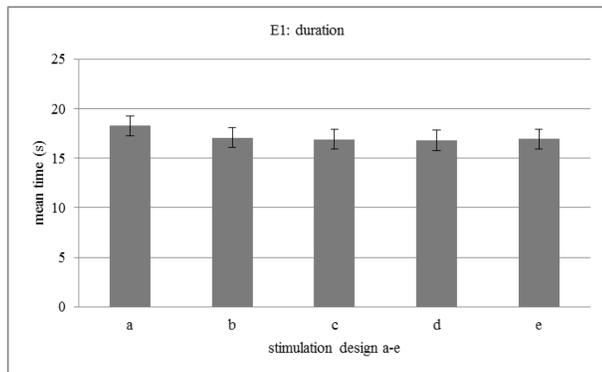


Figure 2: E1- duration

E1: performance

Performance qualities were best with waltz-music (*mean p (d)=0.1*) and with multisensorial stimulation (*mean p (e)=0.1*) and weakest without any stimulation (*mean p (a)=0.35*). A standard deviation of 0.27 was given. Effects were not significant (see Fig. 3).

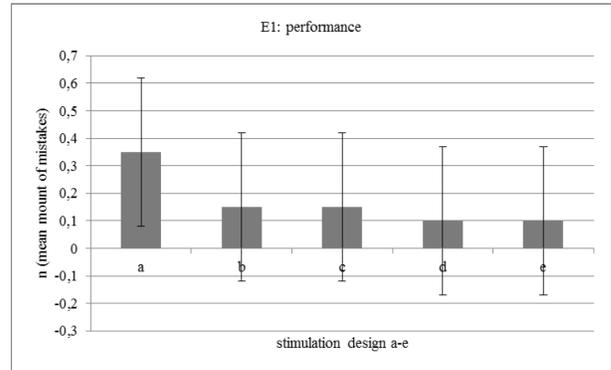


Figure 3: E1- performance

E1: mood

Mood was rated best during waltz-music (*mean mood (d)=3.67*) followed by no stimulation (*mean mood (a)=2.57*). In relation to the pre-assessed initial mood, waltz-music gained still a higher value (*mean mood (0)=3.65*). Weakest results were gained for multisensorial stimulation (*mean mood (e)=-0.04*). A standard deviation of 1.37 was given. Waltz-music lead to significantly higher mood ratings than multisensorial stimulation (p-value=0.392) (see Fig. 4).

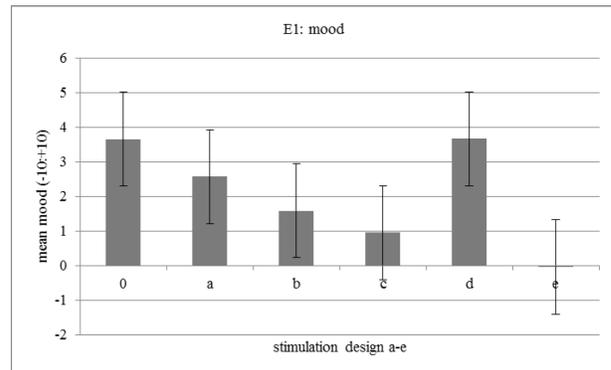


Figure 4: E1- mood

4.2. Experiment 2

E2: duration

In E2 best duration was measured with metronome (*mean time (b)=25.1s*) and weakest without any stimulation (*mean time (a)=32.1s*). A standard deviation of 0.77 was given. Effects were not significant (see Fig. 5).

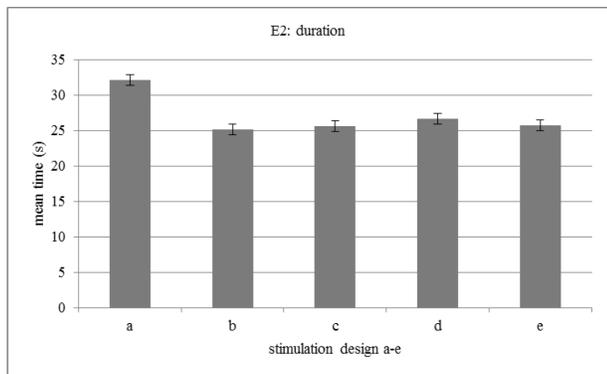


Figure 5: E2- duration

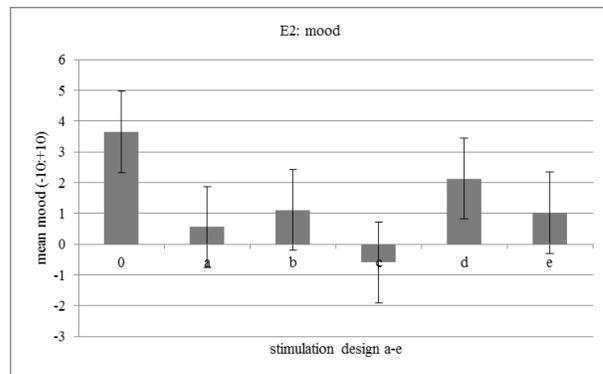


Figure 7: E2- mood

E2: performance

Performance qualities were best with metronome (*mean p (b)= 0.1*) and with multisensorial stimulation (*mean p (d)= 0.1*) and weakest without any stimulation (*mean p (a)= 0.4*). A standard deviation of 0.26 was given. Effects were not significant (see Fig. 6).

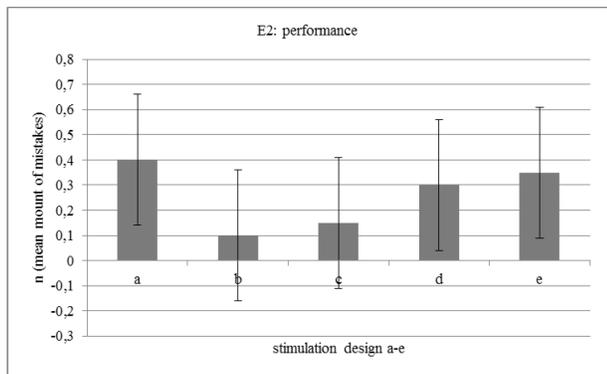


Figure 6: E2- performance

E2: mood

Mood was best during waltz-music (*mean mood (d)= 2.14*) whereby the initial mood before any task was performed was still higher (*mean mood (0)= 3.65*). Weakest results were gained with spearcon-beat (*mean mood (c)= -0.59*). A standard deviation of 1.32 was given. Effects were not significant (see Fig. 7).

4.3. Experiment 3

E3: duration

In E3 best t was assessed with metronome (*mean time (b)= 73.5s*), followed by spearcon-beat stimulation (*mean time (b)= 73.6s*). Weakest duration times were measured without any stimulation (*mean time (a)= 105.6s*). A standard deviation of 12.12 was given. Effects were not significant (see Fig. 8).

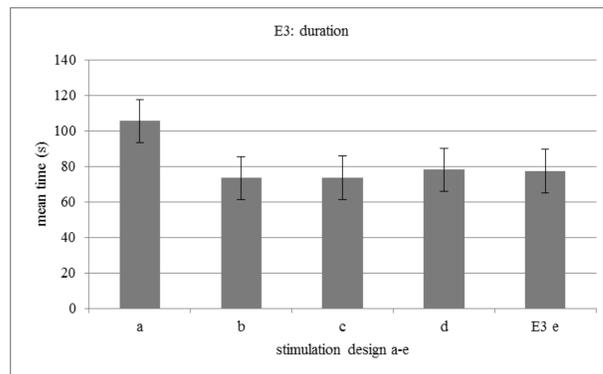


Figure 8: E3- duration

E3: performance

Performance qualities were best with metronome (*mean p (b)= 1.05*) followed by multisensorial stimulation (*mean p (d)= 1.15*) and weakest without any stimulation (*mean p (a)= 1.4*), followed by waltz-music (*mean p (d)= 1,35*). A standard deviation of 0.13 was given (see Fig. 9). Effects were not significant.

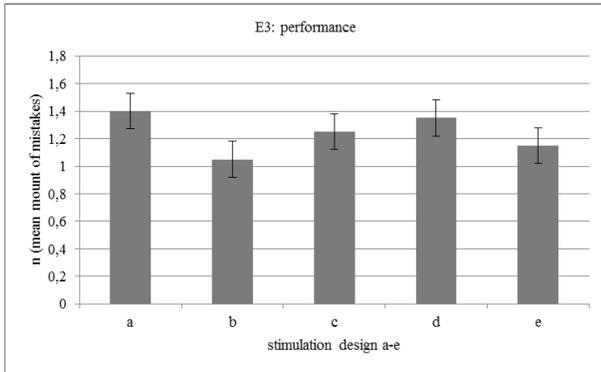


Figure 9: E3- performance

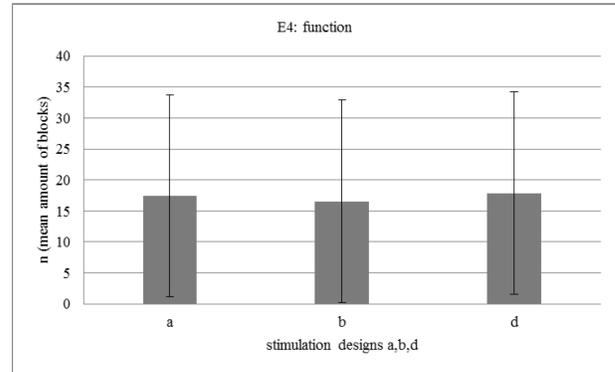


Figure 11: E4- function

E3: mood

Mood was rated highest with waltz-music (*mean mood (d)*= 2.09), whereby the initial mood before any task was performed was still higher (*mean mood (0)*= 3.65). Weakest results were gained with spearcon beat (*mean mood (c)*= -0.25). A standard deviation of 1.35 was given. Effects were not significant (see Fig. 10).

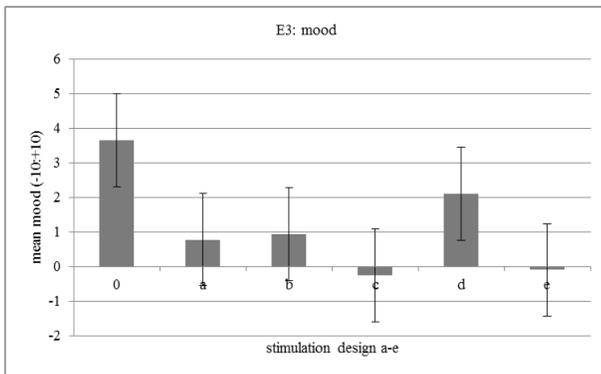


Figure 10: E3- mood

4.4. Experiment 4

E4: function

In E4 the highest amount of blocks was achieved during stimulation with waltz-music (*mean amount (d)*= 17.8), followed by no stimulation (*mean amount (a)*= 17.4). The lowest amount of blocks was seen with metronome (*mean amount (b)*= 16.6). A standard deviation of 16.3 was given. Effects were not significant (see Fig. 11).

5. DISCUSSION

Results of E1-3 were not showing significant effects of a specified rhythmic stimulation design on duration and performance. Still, duration and performance were weakest without stimulation in comparison to additional stimulation throughout all experiments with healthy subjects. This may indicate that RAS enhances velocity and performance qualities applied during a fine motor task in healthy subjects, independently of the level of difficulty.

Mood ratings were highest with waltz-music in comparison to no stimulation, whereby the initial mood, before any task was performed, was still better in E2 and E3. In E1 mood was rated even higher with waltz-music than the initial mood. Waltz-music potentially enhanced the mood whether a task had to be performed what might show that waltz-music was perceived as motivating generally. Mood was rated second best with metronome. In easy conditions given E1, the second best results in mood ratings were seen without any stimulation. In more difficult tasks like in E2 and E3, mood was second best with metronome. Potentially the metronome stimulus was perceived as most neutral during an energy taking task that demands concentration. This could also be related to good results gained with metronome in duration and performance:

In E2 and E3 metronome showed best results in comparison to other RAS-designs and to no stimulation. In E4 with patients best functional outcome was seen with waltz-music, followed by no stimulation, and weakest results were gained with metronome. Metronome lead to lowest functional outcome here, what might be due to the tempo of 200bpm which was applied like in E1-3 with healthy subjects during the NHPT. The tempo was chosen in relation to the NHPT standard value table with a speed-up rate of 20%. Patients commented this stimulation design as stressful, what could be one reason. Another experiment should be performed in which the stimulation-tempo

should be related to a pre-assessed performance tempo of a patient with a speed-up rate of 20%.

To provide sound design for RT that enhances recovery, function and motivation have to be taken into account carefully. A simple stimulus like a metronome could serve as a stable rhythmic cue during difficult tasks, if provided in a tempo evaluated adequately.

Throughout all experiments mood was rated to be highest with waltz-music independently of the level of difficulty, and patients performed the test with waltz-music best. Särkämö et al. (2002) showed that even just passive music listening of pleasant music may rise mood levels in stroke patients [22]. This might in turn influence motivation during training. As a special focus in research on rehabilitation robotics is the proposition of an engaging technical environment that promotes high motivation, effects of music on mood during the experiments should be considered as very important.

In contrast to that, multisensorial stimulation led to lower qualities in comparison to other designs in all conditions. A reason for that could be technical limitations of the prototype which generated hits on the foot. These hits were described as distracting by many participants. As mood levels were rated strongly negative under this condition, and negative effects on function were assessed in comparison to other designs, rhythmic multisensorial stimulation was excluded for further investigations.

No strong effects were seen with spearcon-beat. Test participants described the spearcon-beat as distracting due to asthetical reasons. Because of that, also the spearcon-beat was excluded for further observations.

6. CONCLUSION

The main goal of this article was to introduce specified rhythmic stimulation designs for robotic rehabilitation hand function training (RT) that promote functional and motivational effects for stroke patients. A review on effects of sound in technically-assisted motor rehabilitation was taken into account to translate promising sound designs into the context of RT: As “Rhythmic Acoustic Stimulation” (RAS) was shown to be highly efficient in enhancing motor control and movement initiation for neurological patients, four pilot experiments were conducted to examine effects of specified rhythmic stimulation designs for RT.

Results of three experiments with healthy subjects indicate that rhythmic stimulation could enhance velocity profiles and performance as it was seen in all suggested stimulation designs in comparison to no stimulation. With metronome healthy subjects showed better performance, especially throughout difficult tasks. In the easiest task best functional results were gained with waltz-music. Musical stimulation gained best mood ratings, independently of the

degree of difficulty. Functional aspects were weaker with waltz-music than under metronome stimulation or the spearcon-beat. Two sound designs were concluded from results gained in three experiments with healthy test persons for a fourth experiment with stroke- patients. Patients showed best functional results with waltz-music, followed by no stimulation. Weakest results were seen with metronome. This might be due to the provided tempo which was applied like in previous experiments with healthy subjects. Further experiments are needed to evaluate effects of slower tempi with patients.

As results indicate RAS improves function and motivation, waltz-music, and/or metronome are proposed for observations in RT. More research on effectiveness of sound in technology-assisted motor rehabilitation is needed to promote recovery, to enhance given designs, and to inform further applications in the field of motor rehabilitation. Therefore RAS, music, auditory feedback, and combinations of these promising auditory stimuli are concluded for future explorations.

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