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Sensorized assessment of bilateral hand movements in patients with stroke driven by rhythmic auditory or visual-auditory stimulation

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There is a growing body of literature about the efficacy in neurorehabilitation of the devices providing rhythmic auditory stimulations or visual-auditory stimulations, such as videogames, for guiding the patients' movements. Despite being presented as tools able to motivate patients, their efficacy was not been proven yet, probably due to the limited knowledge about the factors influencing the capability of patients to move the upper limbs following an external stimulus. In this study, we used a marker less system based on two infrared sensors to assess the kinematics of up and down in-phase and anti-phase bilateral hand oscillations synchronized or not with an external stimulus. A group of stroke survivors, one of age-matched healthy subjects and one of young healthy subjects were tested in three conditions: no stimulus, auditory stimulus, and video-auditory stimulus. Our results showed significant negative effects of visual-auditory stimulus in the frequency of movements (p = 0.001), and of auditory stimulus in their fluidity (p = 0.013). These results are conceivably related to the attentional overload required during the execution of bilateral movements driven by an external stimulus. However, a positive effect of external stimulus was found in increasing the range of movements of the less functional hand in all subjects (p = 0.023). These findings highlight as the type of stimulus may play a crucial role in the patient's performance with respect to movements that are not-externally driven.

In recent years, neurorehabilitation has been supported more and more by technological devices. The movements previously asked of the patients by the physiotherapist to the patients, and manually assisted as needed, often became guided by an external stimulus, such as in training based on rhythmic auditory stimuli (1, 2) or in video-game based therapy (3, 4). These approaches provide auditory or visual-auditory stimuli with the idea that these stimuli act as facilitators in neurorehabilitation. Some studies reported motor but also cognitive improvements following video-game based therapy especially in stroke survivors (4, 5), even though conclusive evidence is still needed (3). Some studies were related to a single hand approach, with the task involving only the paretic side (6, 7). Other studies had a bilateral approach with the non-paretic hand useful for helping and guiding the movements of the paretic one (8). However, the role of the non-paretic hand could more so, be related to neural networks. Kinaesthetic afferences from one limb can influence the motor pathways to the other one (9-12).

Key words: rhythmic auditory stimulation, visual-auditory stimulation, video-game based therapy, neurorehabilitation

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The orchestration of simultaneous reaching movements could be controlled by one single motor program, because of the isomorphic movements of two limbs (13). Furthermore, coupled bimanual training, in stroke survivors, has proven as a therapeutic intervention more effective than the unilateral training of the impaired hand (14-15). Some other studies reported a positive training effect of the non-affected hand on the affected hand thanks to the so-called bilateral transfer, id test, the ability to transfer the skill acquired with a hand to the other one (16).

The type of bilateral movement is also crucial. Some studies have shown as in-phase bilateral movements are easier to perform than anti-phase movements (17-19). A recent study showed as similar parameters between single hand movements and in-phase coupled movements, whereas anti-phase coupled movements resulted less ample, less sinusoidal but more frequent with respect to single hand movements (20). These features were particularly evident for stroke survivors who in general showed reduced similarity of bilateral movements in all conditions, but especially for anti-phase movements performed under visual control (20). Visuomotor integration in patients who suffered a stroke could be less effective than in healthy subjects, probably because of the attentional overload required by the two limbs moving in an alternating fashion (20). The capacity of such patients to interact with external stimuli (visual or visual-auditory), such as during video-game based therapy may therefore be questioned. Furthermore, also age could play a role for its influence on the visuo-motor integration: older adults typically use visual information less effectively than younger adults to reduce force control error in bimanual pinch tasks (21).

The aim of this study was to investigate the performance of manual and bimanual movements when stroke survivors were asked to follow either a rhythmic auditory or visual-auditory stimulation.

MATERIALS AND METHODS

Participants

Seventy-six participants (40 females: 53%) were enrolled in this study: 48 young healthy adults (YG, mean age: 27±5), 10 stroke survivors (PG, mean age: 63±11, time from stroke: 105±82 days), and 18 healthy adults age-matched with patients (AG, mean age: 58±11, p=0.278). Inclusion criteria for the healthy subjects were the age (YG: 18-39; AG: 40-80), the absence of any motor or cognitive pathology, and normal vision or corrected for normal with glasses. The inclusion criteria for the patients were a positive clinical diagnosis of stroke confirmed by neuroimaging, age between 40 and 80 years old, a time from acute event lower than 9 months, the presence of residual movement of paretic hand allowing to perform the task. Exclusion criteria were comorbidities such as parkinsonisms or orthopaedic pathologies of upper limb, moderate to severe cognitive deficits (highlighted by a Mini-Mental State test score <24), and presence of unilateral spatial neglect. The study was approved by the Independent Local Ethical Committee and all the participants provided the signed informed consent.

Experimental tasks

The experimental set-up was the same as one used in a previous study on bilateral coordination with and without visual control (20). Participants sat in front of a table on which the sensor platform was placed and were asked not to move their trunk from the back of the chair. Each participant was asked to oscillate up and down his/her hands over two sensors, up until a maximum height shown by a horizontal sign on a vertical bar placed in proximity to the sensors was reached. Subjects were required to perform bilateral movements with the hands kept horizontal and the palms downward, under different conditions. Three stimulation responses were instructed: 1) no stimulus to follow (NS), just spontaneous movements at self-selected comfortable speed, 2) to follow the rhythm of an auditory stimulus (AS), the frequency of which was set as the same of the NS condition, 3) to follow the rhythm of a visual-auditory stimulation (VAS), the frequency of which was set as the same of NS. From a motor point of view, two possible conditions were required: to perform the bilateral movement in-phase or in anti-phase between the two hands. The order of AS and VAS or of the in-phase and anti-phase conditions was randomized among subjects. The Researcher showed how to perform the task to participants, the simplicity of which allowed them to start the test without any training. Hence, six different conditions were possible. The less functional hand was considered that clinically assessed as paretic for patients who suffered a stroke and the non-dominant hand for healthy subjects as evaluated by means of the Edinburgh Handedness Inventory (22).

Instrumental apparatus

We used a Distance-Multi-Sensing platform, integrating a magnetic and inertial measurement unit with a couple of Infrared Time-of-Flight (IR-ToF) proximity sensors. The IR-ToF provides an estimate of the distance between the sensor and the target (the hand) based on the time that an electromagnetic wave takes to travel that distance estimated by measuring the phase shift between the emitted and the reflected signals (23). It allowed it to avoid the use of sensors placed on the hands, that could alter the ecological performance of subjects. The accuracy of these marker less systems has already been validated in human movement analysis (24-25). The two IR-ToF sensors were used to evaluate the distances of both hands from the table on which the platform was placed. According to a previous study (20), the sampling frequency of the IR-ToF proximity sensors was set at 25Hz.

The duration of each trial was of 30s, but the first and last part of the trial were not analyzed to avoid including accelerating and decelerating portions of the signal: for each trial, at least 15s of the steady state of the signal in the middle part of the trial were analyzed. Then, the recorded data were low pass filtered at 5 Hz using a fourth order Butterworth filter. Both hands were recorded and the filtered signal obtained by each hand was fitted with a sinusoidal curve recording the amplitude and frequency of the fitting curve, with the relevant R^2 used as an indicator of how much the movement was represented by its first sinusoidal harmonic. Two commercial apps were used on a 10-inch screen tablet (with a 10 inches-screen) to provide the rhythmic auditory stimulation (with an app simulating the sound of a metronome) and visual-auditory stimulation (with an app showing a bouncing balls together with a sounds, similar to that of a metronome, for each bounce).

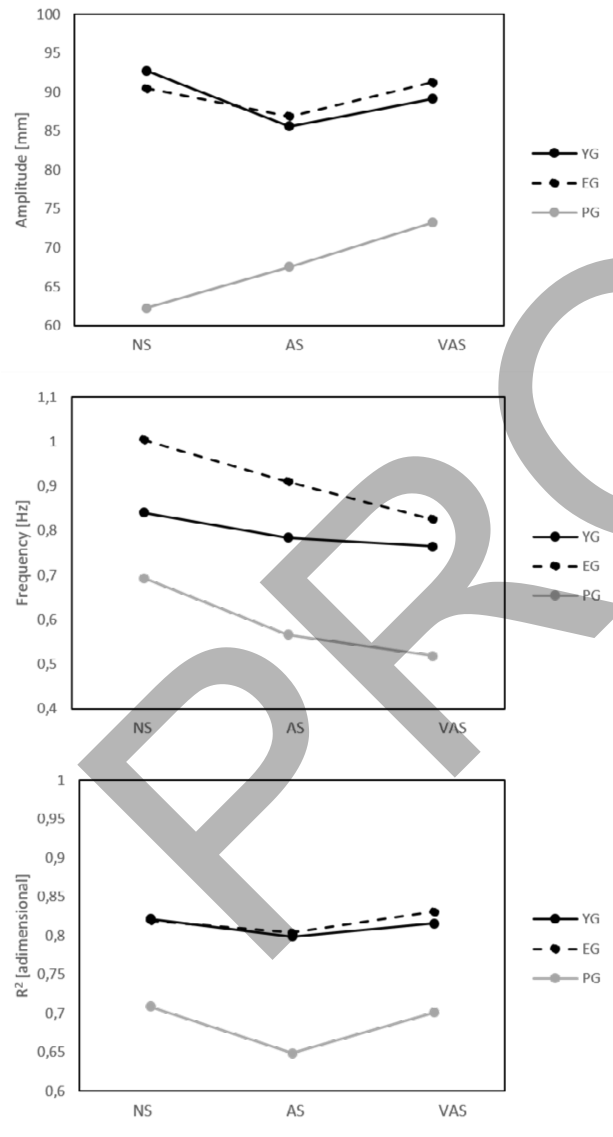

Fig. 1. *Mean data for amplitude **(above)**, frequency **(middle)**, and R2 **(below)** for the young **(YG, solid black lines)**, elderly **(EG, dotted black lines)**, and patient group (**PG, grey lines**) in the three conditions: No Stimulus (**NS**), Auditory Stimulus (**AS**) and Visual-Auditory Stimulus (**VAS**).*

Statistical analysis

Data were reported in terms of mean and standard deviation. A mixed Analysis of Variance (Anova) was used for assessing the effects of the group as between-subjects factor and of motor and visual conditions as within subjects' factors. Effect size (ES) was also evaluated as partial eta squared, representing the proportion of variance attributed to one effect. For all these analyses the alpha level of significance was set at 5%.

RESULTS

In Fig. 1 the computed parameters with respect to the main effects of the factor group and type of stimulus are shown. Some other parameters are not reported in the figure but were analysed. As expected, the performances of patients were generally lower, but the group factor not always lead to a statistically significant difference. For example, despite the amplitude of movements was numerically lower in patients, the effect of the group main factor was not statistically significant. In fact, Anova showed that the Amplitude of movements factor was only close to the statistically significant threshold among the three groups (F=2.618, p=0.080, ES=0.067). Furthermore, no significant differences were found between the two hands (side effect: F=0.750, p=0.389, ES=0.010), among the three conditions (F=0.225, p=0.109, ES=0.030), or between the in-phase and the anti-phase movements (F=1.044, p=0.310, ES=0.014). Neither the second level nor the third level interactions showed statistically significant results (p>0.05), but the side per phase interaction did (F=5.414, p=0.023, ES=0.069); note that this interaction is neither related to the group nor to the stimulus condition factors. The side per condition interaction was related to a difference in VAS condition between higher amplitudes of the more functional hand versus lower functional hand, independently of group.

Conversely, frequency of movements resulted significantly different among the three conditions (F=7.347, p=0.001, ES=0.091), with the visual feedback associated to a lower frequency (Fig. 1). No significant differences were found for the other factors such as side (F=0.252, p=0.618, ES=0.003), phase (F=0.242 p=0.625, ES=0.003), group (F=2.337, p=0.104, ES=0.060), or their interactions (p>0.05 for all of them).

Condition also significantly influenced the sinusoidal waveform of movements (R^2: F=4.448, p=0.013, ES=0.057), that resulted also significantly different among the three groups (F=10.687, p<0.001, ES=0.226) and between in-phase vs. anti-phase movements (F=11.080, p=0.001, ES=0.132). R^2 did not result significantly affected by side (F=0.009, p=.925, ES=0.001) or by the interactions among the above variables (p>0.05).

DISCUSSION

The several conditions presented in this work and the relevant analysis require a thorough discussion. The main interest of this study was to investigate the different effects of different types of stimulus. The VAS condition showed a frequency of movements significantly reduced and wider movements for patients (even though it was not statistically significant). Then, the sinusoidal waveform was reduced only in the AS condition. Anti-phase movements resulted even less sinusoidal, in accordance with a vast amount of literature (17-20). This effect was explained with the simultaneous and symmetrical recruitment of muscle groups occurring during in-phase movements that may lead to more accurate and effortless movements than anti-phase ones, in which homologous muscle groups are activated in an alternating fashion (17-19). As expected, the performance was lower in patients. However, the main effect of group was statistically significant only for R^2 revealing that the waveform of hand movements was less sinusoidal in patients than in the two enrolled healthy groups.

These results can be summarized in a significant negative effect of external stimulus for guiding bilateral movements, of the VAS condition on the frequency of movements and of AS on the fluidity of movements. However, despite only close to statistical significance, a positive effect of VAS was observed on the movement amplitude, especially in patients. This effect was significant only for least functional hand independent on the group (paretic hand in patients and non-dominant hand in healthy subjects).

Despite complex because of the many factors involved, our findings may provide interesting insights on movements synchronized with external stimuli. Video-game based therapy has been often reported as highly motivating patients who suffered a stroke (26), but a higher efficacy of interactive video-gaming and virtual reality with respect to conventional therapy has not been convincingly proven (3). Indeed, external stimuli might require an attentional workload that shifts the patient cognitive attention from the execution of the movement to the recording of the stimulus.

Our study supported the idea that visual-auditory stimuli, such as those of videogames, may improve some kinematic parameters, such as movement amplitude, and possibly increase the range of motion, but less for enhancing speed. This may confirm the idea that the external stimulus should be simple and slow. It is also in line with the recent results of a similar study showing that visual feedback has a positive effect on increasing amplitude of movements without changing their sinusoidal regularity (20). Furthermore, visual control plays a fundamental role for managing bimanual tasks (21).

Another aspect to take into account by designers, involved in the development of bilateral devices for neurorehabilitation having auditory or visual-auditory stimuli, is that anti-phase movements are often more difficult and require training to be accurately performed (27). Furthermore, during fast anti-phase movements, people unintentionally tend to change into in-phase movements (28).

Our study has some limitations suggesting caution in data interpretation. First, the sample size was small especially for PG, making impossible to differentiate among different types and severity of stroke. Another limitation was that the visual control during VAS condition was not taken into account; by contrast, it could be very interesting, in further studies, to investigate as to whether the attention of subjects was only on the video monitor or also shifted on hands.

In conclusion, our study confirmed previous results showing that in-phase coupled movements were more synchronized than anti-phase movements in all subjects and added that external stimuli not always act as facilitators, despite being very simple. Video-game programmers involved in the development of neurorehabilitation devices should carefully take into account the findings of our study for understanding how the type of the stimuli and the relevant attentional overload may improve or worsen the performance of patients who suffered a stroke.

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