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Visuo-Vibrotactile Stimuli Applied for Skills Transfer and Rehabilitation

Ignacio HERRERA-AGUILAR[a], Osvaldo SANDOVAL-GONZALEZ[a], Blanca GONZALEZ-SANCHEZ, Juan JACINTO-VILLEGAS, Alejandro Rodríguez-González[c], Giner ALOR-HERNANDEZ [a] and Otniel PORTILLO-RODRIGUEZ[b]

[a] *Instituto Tecnológico de Orizaba, DEPI, Orizaba, Veracruz México*
[b] *Universidad Autónoma del Estado de México, Facultad de Ingeniería, Toluca, México*
[c] *Computer Science Department, University Carlos III of Madrid, Spain*

Abstract. This paper presents the static and dynamic analysis of visuo-vibrotactile feedback used like skills accelerator for motor skills training. Through this chapter, two experiments are presented in order to evaluate in different fields the use of this skills accelerator. In the first part it was performed a static psychophysics analysis of vibrotactile feedback to understand in details the accuracy in perception under determined conditions like intensity and frequency level. In the second part is presented a dynamic analysis of vibrotactile feedback where the use of diverse stimuli (visual and vibrotactile) are evaluated to understand how these kinds of stimuli can affects the performances of one motor activity under determined conditions. The results indicate improvements of the user's movements using in vibration in certain parameters in order to be useful like a skills accelerator.

Keywords. vibrotactile stimuli, skills transfer, rehabilitation

Introduction

Physical rehabilitation of patients with some form of paralysis and disability is hard work. The paralysis or disability can be caused by various causes, such as stroke, in Mexico there are almost 2.5 millions of people with motor disabilities, these people need rehabilitation therapies and they require specialized equipment to ensure their rehabilitation [1]. The mechanoreceptors in the skins make humans feel different tactile sensations when touching objects. When an object is touched, these sensations are combinations of tactile primitives like the normal indentation, lateral skin stretch, relative tangential motion and vibration. Different researches have explored the tactile sensation as a modality to present information for orientation and navigation in Virtual Environments [2] [3] . Lieberman and Breazeal carried out an experiment in real time with a vibrotactile feedback in a Virtual Environment to compensate the movements and accelerate the human motion learning [4]. In the same line of research Bloomfield performed a Virtual Training via Vibrotactile Arrays [3]. Both experiments show a significant improvement in the human cognition and perception. The vibrotactile feedback in human motion has been widely investigated with different perspectives in the application. Van Erp [6] explores the possibilities of tactile displays in sports applications, and reports an experiment that shows that a tactile feedback system improves rowing efficiency compared to traditional feedback systems. Earlier papers have shown that localized vibrations provide intuitive cues for orientation and navigation. The application of vibration in physical therapies has been widely used. On example of these researches was done by Lindeman [7] that presents a work in the context of a physical therapy application designed to provide more autonomy for patients when performing rehabilitative exercises. This assistive technology has the potential to reduce injuries during therapy due to improper patient joint movement, and decrease the workload of physical therapists, thereby reducing healthcare costs. All these researches have obtained interesting results using vibrotactile devices in human motion skills. However, there is a big area of research in the psychophysics field. Because, it is important to understand the behavior of the human perception under determined conditions like type of movement, velocity of movement, type of vibration, location of the vibrotactile devices and the correlation among different senses like audio and vision.

1. Description of the system

The vibrotactile control system was specially designed to control the vibration in intensity (vibrational acceleration) and pulses of frequency (train of pulses) of four motors. The system presented in Fig 1 consists of one Microchip microcontroller (PIC18F4431) capable to control four PWMs (Pulse Width Modulator) in hardware level with a 12-bit resolution. The power control section uses an IC ULN2803 (Darlington transistors array) which modules the total amount of energy through the PWMs that are applied to the vibration motors. There are two types of communications available: Bluetooth and USB protocols. These protocols transmit the information from the computer to the microcontroller. The vibration motors correspond to the model 12mm Shaftless Vibration Motor of the Precision Microdrives Company [8]. The motor has a nominal speed of 9000rpm generating a vibration of .9G with a current consumption of 120mA as it is presented in Fig 2. The strategy consists in the generation of four PWM signals of 4KHz frequency for each one of the four motors. For the control of vibration in intensity, the microcontroller receives from the computer the parameters of each one of the duty-cycles (0-4096). Once the microcontroller has acquired the values, modulates the duty-cycle of each PWM and send this information to the Electronic Power Circuit ULN2803. This device is a Darlington transistors array that is a compound structure consisting of two bipolar transistors connected in such a way that the current amplified by the first transistor is amplified further by the second one. This configuration gives a much higher current gain (written β, hfe, or hFE) than each transistor taken separately.

Fig 1. Vibrotactile System

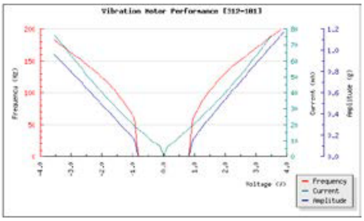


Fig 2. Vibration motor

2. Experiments

The aim of these pyschophysics experiments is to analyze the human perception under determined vibrotactile stimuli. These analyses are an opportunity to know in detail different information about the interaction between the human perception using visuo-vibrotactile stimuli and how could be used like skill accelerator in the learning process of one motor skills activity and rehabilitation. A couple of set experiments (static and dynamic) were carried out in order to understand the human behavior under determined stimuli. On one hand the static analysis is based on the psychophysics experiments of sensitivity of vibration in different modalities. In the other hand the dynamic analysis using visuo-vibrotactile feedback is evaluated during the performance of motor-skills activities.

2.1. Static Analysis of the Vibration's Intensity and Frequency using vibrotactile stimuli

The aim of this set of experiments was to know in detail the human perception using two types of vibration stimuli: intensity and frequency. On one hand, the intensity of the vibration is manipulated through the modulation of the energy delivered to the actuators from 0 to 3.8V in order to vary the rotational speed of the device from 0 to 9000rpm and the r.m.s. acceleration from 0 to 0.6382 mm/sec^2 and constant high frequency of 4KHz. In the other hand, the second vibration consist of a stimuli generated like a train of pulses of low frequency from 0 to 50Hz and acceleration of 0.5mm/sec^2. The experiments were divided in 2 sections. On one hand, the analysis of the inflexion points of sensitivity to determine the linear and non linear zones of the vibrotactile perception is analyzed. In the other hand a psychophysics analysis of vibrotactile sensitivity in intensity and frequency is carried out to determine the ranges of sensitivity according to the zones of contact, the surface area of contact and type of vibrotactile stimuli. In Table 1 is presented thee experiment that were carried out by 6 groups of 15 people were formed and divided depending of the contact area and contact place of the vibrotactile devices. During the experiment, all the people carried out 4 experiments (0.25m/sec^2, 0.5m/sec^2, 10Hz and 20Hz) and 30 trials of each one. The system in each one of the 30 trials renders two stimuli: one represents the pattern stimuli and another one is a stimulus generated by the Weibull function which varies the value of the stimuli according the previous responses of the user. Both stimuli are rendered in a random order in each trial, in the same way all the users carried out the 4 sections of the experiments in random order to avoid any kind of learning or adaptation of the stimuli.

Table 1. Experiments performed by 6 groups in order to identify the sensitivity in the vibration using the intensity and the frequency and the size of the surface area

Group	People	Contact Area	Place	0.25 m/sec^2	0.25 m/sec^2	10 Hz	20 Hz
1	15	226mm^2	Finger	30 trials	30 trials	30 trials	30 trials
2	15	452mm^2	Finger	30 trials	30 trials	30 trials	30 trials
3	15	226mm^2	Forearm	30 trials	30 trials	30 trials	30 trials
4	15	452mm^2	Forearm	30 trials	30 trials	30 trials	30 trials
5	15	226mm^2	Leg	30 trials	30 trials	30 trials	30 trials
6	15	452mm^2	Leg	30 trials	30 trials	30 trials	30 trials

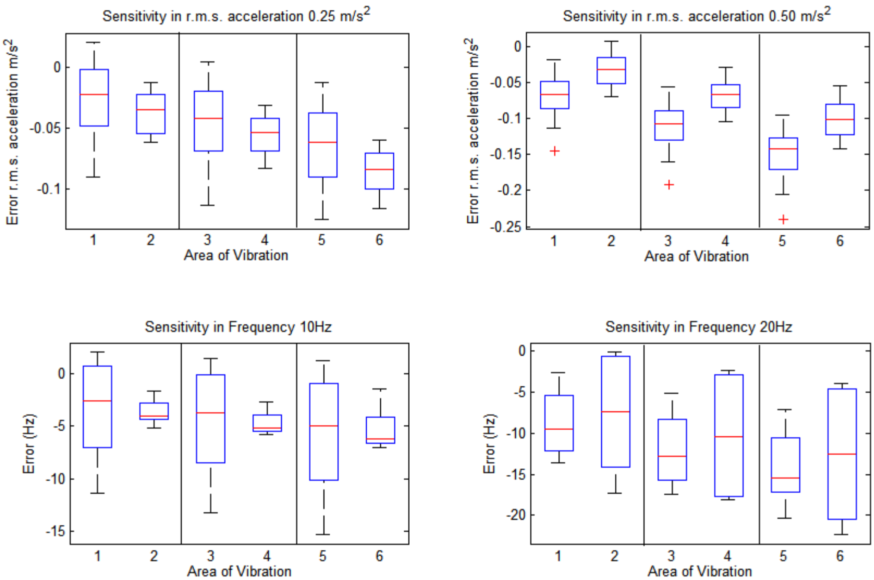


Fig 3. There are 4 plots which represent the vibration in Intensity (0.25m/s^2 and 0.5m/s^2) and Frequency 10Hz and 20 Hz in a contact area of 226mm^2 and 452mm^2. Contact Place: (1) Finger 226mm^2, (2) Finger 452mm^2, (3) Forearm 226mm^2, (4) Forearm 452mm^2, (5) Leg 226mm^2, (6) Leg 452mm^2.

The results presented in Fig 3 generated by the perception of the user about vibration in intensity (acceleration) and frequency (train of pulses) shows that the improvement in the perception when the area is stimulated at 452mm^2 is using an acceleration of 0.50m/s^2 and frequency of 20Hz. Meanwhile in low intensity of 0.25m/s^2 (acceleration) and frequency of 10Hz the results were better using a contact area of 226mm^2. As it was expected the best results in the four tests were obtained by the finger and the worst were obtained by the upper-leg. The important point to comment is that perception of all these zones is located in an acceptable range of sensitivity, and that is important because these areas can be used for training purposes through vibrotactile stimulation, knowing in advance that the users will feel the variation in the simulation during the training. The second important topic to review is the perception according to the type of stimuli. In one hand, the vibration in intensity produced by the r.m.s acceleration (0.25 m/sec^2 and 0.5m/sec^2) shows that it is better to work with moderate intensity. The users presented better sensitivity using a stimulus of 0.25 m/sec^2 rather than the stimuli of 0.5m/sec^2. The possible explanation could be that the stimuli saturate the mechanoreceptors at high intensities. It is well known that the human perception presents a non-linear behavior. However, the importance of these experiments is to analyze the zones which present the closest linear response. The error in perception increases with a non-linear behavior when the stimulus is less than 0.25 m/sec^2 or higher than 0.5m/sec^2.

2.2. Dynamic Analysis of Visuo-Vibrotactile Feedback as an accelerators in Motor Skills Training

Human motion is a fundamental part for the accurate performance in one activity. In the traditional process of learning human beings apply the imitation process to acquire the skills of one activity. Undoubtedly, the visual imitation process has demonstrated a natural instinct action for the acquisition of knowledge. However, although the vision process is one of the most effective and accurate sense to process the information and learn through the imitation, there is one important issue; the vision consumes many resources for the normal brain functionality. It means that the performance in the imitation process depends not only of the type of movement but also in the speed of the type activity. However, the integration of other senses like tactile sense could offer the possibility to augment the perception of the users and help them to perform the activity in an accurate way. The aim of this experiment is to analyse the visual and visuo-vibration feedback in the cognitive process of human being. Vibration is used like a collision feedback to transmit information of a trajectory. In this experiment the goal is to know the correlation between tactile-perception and motor skills performed by user in cognitive process in the brain. During the experiment the user must follow a predefined trajectory plotted in the screen with the movement of his/her hand. The experiment consists of a set of simple linear trajectories. Each trajectory has execution time classified in slow, normal and fast speed (20cm/sec, 40cm/sec and 60 cm/sec). The methodology is based on the idea of collision perception, in other words the user will feel vibration if they are performing the movement in an incorrect position. As is shown in Fig 4 a vibrotactile feedback system will be placed in the wrist of the person. These vibration motors are located in the frontal and back face of the wrist and they will render a proportional vibration depending of the error from 0 to 0.5m/sec^2. During the experiment the participants will carry out seven trials in a random sequence. Each one of these trials corresponds to different kind of visual and visuo-vibrotactile feedback. There is a linear trajectory of 20cm plotted in the screen and the users must follow a pattern sphere in blue color that is moving upwards and downwards with a specific velocity. During each trial of the experiment, the velocity is divided in 3 different speeds (20cm/sec, 40cm/sec and 60 cm/sec).

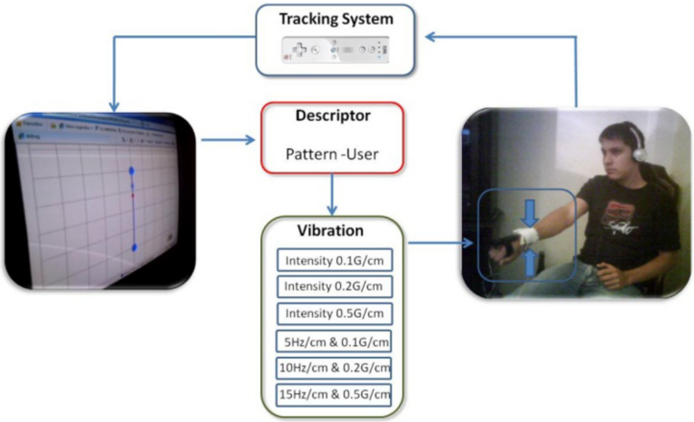


Fig 4. General Structure of the Evaluation

2.2.1. Visual Feedback

This test analyses the motor skills of the user following a simple trajectory by the hand controlled only by vision. The distance of this trajectory is 20cm from top to down. The visual feedback experiment was carried out by 14 people; it was divided in 3 intervals of time (20cm/sec, 40cm/sec and 60 cm/sec). In each interval of time the user must follow the pattern ball in 50 cycles or repetitions. That means that the user carry out 150 repetitions during the complete trial.

2.2.2. Visuo-vibrotactile feedback

This test analyzes the motor skills of the user following a simple trajectory by the arm controlled by visuo-vibrotactile feedback. The distance of this trajectory is 20cm from top to down. This experiment was carried out by 84 people (6 Groups of 14 People); it was divided in 6 tests in 3 intervals of time each. The vibration will act in the following way: If the users perform the movement correctly, the vibration is not rendered. When the actual position of the user is upwards in relation with the pattern position, the vibration motors placed in the frontal face of the wrist will start to vibrate. This vibration will be increased proportionally to the error. This feedback indicates to the user that there is an error in their trajectories and they must move backwards the arm. When the actual position of the user is backwards in relation with the pattern position, the vibration motors placed in the back face of the wrist will start to vibrate. This vibration will be increased proportionally to the error. This feedback indicates to the user that there is an error in their trajectories and they must move back the arm. The 6 tests correspond to the type of vibrotactile stimuli rendered to the users. In Vibration by Intensity there are 3 types of vibration stimuli rendered in intensity form. The stimulus varies proportional to the error in distance generated by the users. These 3 types of vibration are: 0.07 rms m/s^2 per cm, 0.1418 m/s^2 per cm and 0.35 m/s^2 per cm.

In Vibration by Intensity & Frequency there are 3 types of vibration stimuli rendered in intensity & frequency form. In these cases the vibration is changing in intensity and frequency. The user will feel a train of pulses of 5Hz/cm, 10Hz/cm and 15Hz/cm and the intensity of these trains of pulses will vary in : 0.07 rms m/s^2 per cm, 0.1418 m/s^2 per cm and 0.35 m/s^2 per cm depending of the error performed by the user.

3. General Discussion and Analysis of the Results

Fig 5 and Fig 6 shows the results of the visual feedback obtained by the 14 users. It is important to highlight how the error is increased in a proportional way to the velocity in the movement. In a velocity of 60cm/sec the users obtain a huge error of almost 40%. Although the vision is an effective method to follow and control the motor skills activities, it is clear that the efficiency is totally dependent of the velocity and the brain is not capable to process all these visual information and reacts at the appropriate time to correct the trajectories. There is significant difference of 18% of error between the minimum and maximum velocity.

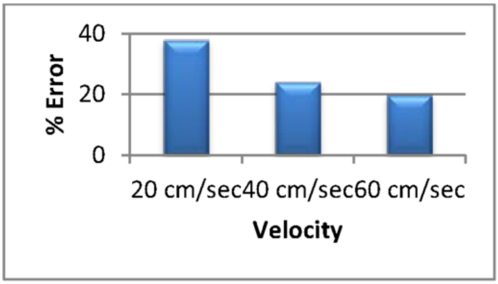


Fig 5. Results of the Visual Feedback in different velocities.

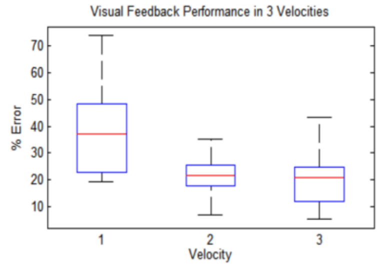
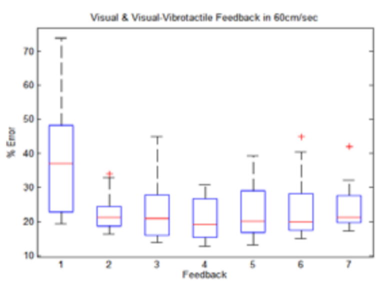
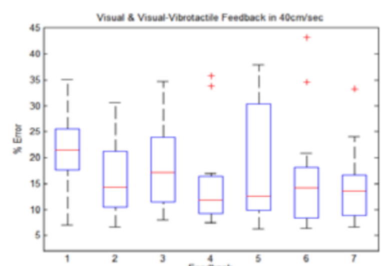


Fig 6. Visual Feedback performance in the 3 velocities. 1) 60cm/sec, 2) 40cm/sec, 3) 20cm/sec

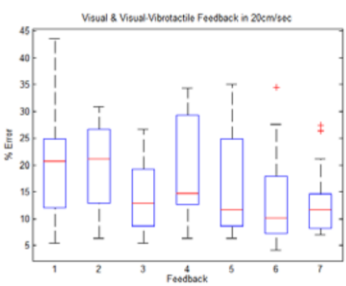
The next analysis shown in Fig 7 (a) (b) (c) presents the results of the seven test using the visual feedback, the three modalities of vibration in intensity and the three modalities of vibration in frequency-intensity in the three different velocities. The maximum errors in the three velocities were obtained by the visual feedback. The best result in 60 cm/sec was obtained by vibration in intensity at $0.35 m/s^2$ per cm with an error of 21.20%. In 40 cm/sec the vibration in frequency-intensity mode 20Hz/cm & $0.35 m/s^2$ per cm obtained the best result with an error of 14.73% and finally in the velocity of 20cm/sec the best performance was obtained again by the vibration in frequency-intensity mode (20Hz/cm & $0.35 m/s^2$) with an error of 13.50%.



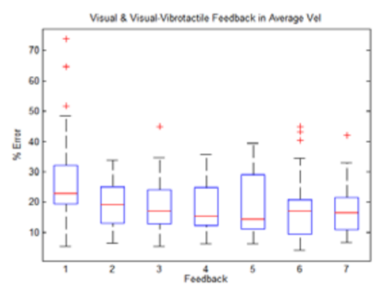
Visual & Visual-Vibrotactile Feedback in 60cm/sec.



Visual & Visual-Vibrotactile Feedback in 40cm/sec.



Visual & Visual-Vibrotactile Feedback in 60cm/sec.



Visual & Visual-Vibrotactile Feedback in Average Velocity.

Fig 7. Visual & Visual-Vibrotactile Feedback in 20cm/sec, 40 cm/sec and 60 cmsec. Feedbacks: 1) Visual, 2) Vis-Vib1, 3) Vis-Vib2, 4) Vis-Vib3, 5) Vis-Vib4, 6) Vis-Vib5, 7) Vis-Vib6.

The interesting point to comment is that although this vibration (vibration in frequency-intensity mode 20Hz/cm & $0.35m/s^2$) have obtained the best results in medium and slow velocity, this feedback obtained the second worst performance in high velocity with 23.85%.

The final analysis, shown in Fig 7 (d), presents the results of the seven feedbacks in an average velocity. In other words the average of the 3 velocities was calculated of each one of the 7 feedbacks. On one hand the visual feedbacks obtain the worst performance with 26.43% of error. In other hand, the best results were obtained by vibration in frequency-intensity mode (20Hz/cm & $0.35m/s^2$) with 17.36% of error.

4. Conclusions

Through the analysis of the results, it can be concluded that as it was observed during the experiments, the use of visuo-vibrotactile feedback produces in all the cases an improvement in the trajectories performed by the users. These vibrotactile feedbacks in high velocities obtained the best improvement reducing the error almost 20% with respect to the visual feedback. The Visual feedback has a big dependency of the velocity of the performed movement. Higher the velocity higher the error. Faster changes in the relation of vibration/error obtain better results for fast movements.

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