Robotic Assisted Hand for Learning a Timing-based Task by the Elderly
Preliminary Results

Amy E. Bouchard[1] and Marie-Helene Milot[2]
[1]*Bishop's University, 2600 College St., Sherbrooke, J1M 1Z7 Québec, Canada*
[2]*Université de Sherbrooke, Faculté de médecine et des sciences de la santé, École de réadaptation, 2500, boulevard de l'Université Sherbrooke, J1K 2R1 Québec, Canada*

1 INTRODUCTION

Timing of movement is crucial in the performance of daily tasks, like playing tennis (Marchal-Crespo et al., 2013). With age, the need to learn new timing tasks persists (e.g. learning to drive a powered wheelchair). However, significant impairments in timing have been noted, like longer execution timing of movements (Seidler et al., 2010) and slower reaction times (Marchal-Crespo et al., 2010).

To improve motor learning, two types of robotic training have been studied: haptic guidance (HG) and error amplification (EA). HG suggests that the learning of a motor task can be enhanced by showing the correct movement in order to teach the motor system how to imitate it (Patton and Mussa-Ivaldi, 2004). EA is based on the idea that error drives learning; by artificially increasing error, a faster and more complete learning can be achieved (Emken and Reinkensmeyer, 2005).

Both types of training have significantly improved the temporal aspect of movement in young healthy people (Luttgen and Heuer, 2013, Marchal-Crespo et al., 2013, Milot et al., 2010). However, few studies have used HG or EA to try to improve movement timing in the elderly.

Up till now, only one study has used HG training to improve seniors' timing. Results showed an improvement in timing when they had to straighten a wheel immediately after turning it (Marchal-Crespo et al., 2010). It seems that no study has directly evaluated and compared the impact of HG and EA on the improvement of timing errors for the elderly.

2 OBJECTIVES

The objective of the current project is to evaluate and compare the impact of HG and EA robotic training types on the immediate improvement in timing error for elders. This project will aid in the understanding of the efficacy of robotic therapy to improve timing for seniors, and help gather reference values for a future study on chronic stroke survivors.

3 METHODS

Subjects had to meet the following criteria: 1) be aged ≥60 years; 2) be able to painlessly flex their right wrist $>10^0$; 3) be right-handed. The exclusion criteria included: 1) having a cognitive impairment (score ≤25/30 on the MoCA exam); 2) having an active neurological or orthopaedic problem of the right upper limb; 3) having a vision problem which would inhibit the proper viewing of the game's computer screen.

3.1 Timing Exerciser Orthosis (TEO)

TEO (Figure 1) is modified from TAPPER, a robot used in one of our previous studies (Milot et al., 2010). TEO is a one-degree-of-freedom robot that is mechanically actuated by a Dynamixel MX-106 actuator (Robotis inc, USA), mounted on an aluminium frame and connected to an articulated hand allowing flexion/extension of the right or left hand. A forearm brace is placed on the frame to ensure the proper stabilization of the subjects. All the apparatuses are connected to a USB-6008 data acquisition card (National Instruments, USA) and sampled at 5000 Hz. A button is also attached to the frame to ensure sensory feedback, since the subjects' fingers touch this button at each movement.

3.2 Pinball Simulator

The pinball simulator was designed with

LabVIEW™ 2013. The goal of the task was to hit as many targets as possible by triggering a wrist movement at the proper timing, to activate TEO (torque ≥ 0.5Nm). When activated, TEO caused the flipper to rotate on the computer screen and lead the falling ball towards a randomly positioned target. Subjects were successful when the ball hit the target at a timing accuracy of 4 ms. Visual feedback was provided to the subjects on each trial (e.g. “Wow! Just on time!” and “Too early! Hit later!”).

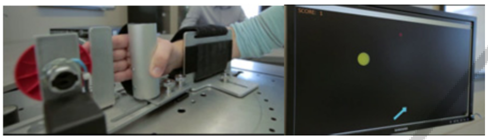

Figure 1: TEO and the computerized pinball-like game.

3.3 Haptic Guidance and Error Amplification Algorithms

To decrease subjects’ timing errors during HG, we delayed or sped up the start of the robot when the subjects initiated wrist movement too early or too late, respectively. The exact opposite was done to increase errors during EA. The algorithms were based on our previous study. In sum, t = 0 was defined as the time the ball began falling toward the flipper, and Tbp was defined as the time in which TEO moved. Now:

$$\mathrm{Tbp} = \mathrm{Tip}+\mathrm{Dc} \quad (1)$$

where Tip is the time the motor sensors detected the initiation of a wrist flexion by the subject and Dc was a programmed delay from when the subject initiated movement to when TEO was commanded to move. For each target, the values that ensured success were defined as Tbd, Tid and so

$$\mathrm{Tbd} = \mathrm{Tid}+\mathrm{Dcd} \quad (2)$$

where Tbd is the anticipated time in which TEO must move in order to successfully hit the target, Tid represents the desired time when the subject should initiate a wrist movement and Dcd is a constant (0.5s).

The subject’s timing error in initiating a movement was defined as Ep, so:

$$\mathrm{Ep} = \mathrm{Tip}-\mathrm{Tid} \quad (3)$$

Next, TEO timing error was defined as Eb:

$$\mathrm{Eb} = \mathrm{Tbp}-\mathrm{Tbd} = \mathrm{Ep}+\mathrm{Dc}-\mathrm{Dcd} \quad (4)$$

We wanted Eb to be proportional to Ep:

$$\mathrm{Eb} = k\mathrm{Ep} \quad (5)$$

where k is the error-amplification gain. Substituting equations 4 into equation 5 and solving for Dc, the programmed delay gave:

$$\mathrm{Dc} = \mathrm{Dcd}+\mathrm{Ep}(k-1) \quad (6)$$

As we wanted each subject to experience a 30% rate of success, we adjusted the k value during a 39-trial adjustment phase. Since Eb’s maximum value was 4 ms (the upper limit of timing accuracy to be successful), the k value was calculated accordingly using equation 5. Therefore:

$$k = 4 /\mathrm{Ep} \quad (7)$$

To do so, we classified each subject’s timing errors in an ascending order and took the 12th Ep value to calculate the final k value. The k value was then increased or decreased by 90% during EA and HG training, respectively, to increase or decrease each subject’s timing error.

3.4 Study Timeline

Each subject received the HG and EA trainings in a random order. First, a baseline condition (B1) was played at the adjusted game difficulty for 40 trials. B1 was followed by either HG or EA each having 75 trials. A retention condition (RC), identical to B1, followed each training condition. The absolute and relative timing error values at B1 and RC were retained. *T*-tests were used to evaluate the difference in timing error between B1 and RC, for each training condition, and for the difference in the change in timing error obtained between both training conditions. The p value was set at 0.05.

4 RESULTS

Eleven subjects (mean age 68±4 years) took part in the study. When comparing the first and last 10 trials of B1, to evaluate the presence of a learning plateau, no change in the subjects’ timing errors were noted (12±7 vs 11 ±4 ms; p=0.2). This means that they had reached a learning plateau before being introduced to the training conditions.

A significant difference in timing error was found when comparing the last 10 trials of B1 with the first 10 trials of HG (12±5 vs 1±0.8 ms; $p<0.05$) and EA (11±4 vs 22±6 ms; $p<0.05$). This means that introducing subjects to HG and EA significantly decreased and increased their timing errors, respectively.

4.1 Impact of HG/EA on Timing Error

When comparing the absolute timing error during RC to that of B1, no improvement in timing error was noted (p>0.14), regardless of the training condition ($t(10)=-1.2$, p=0.13) (Figure 2 A).

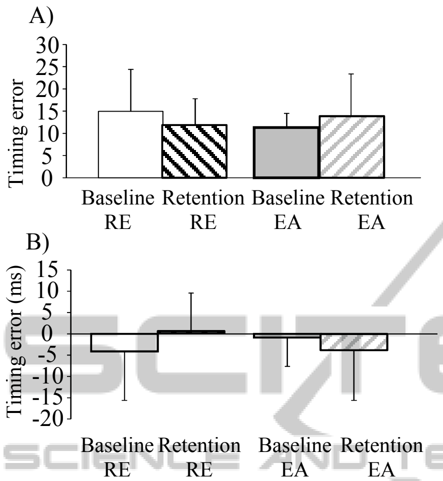

Figure 2: Comparison of subjects' A) absolute and B) relative timing error between the baseline condition and retention condition following HG and EA robotic training.

However, when analyzing the relative timing error, where a negative value indicated that the subjects initiated movement too early, a trend towards an improvement in timing error was noted when comparing B1 to RC following HG training (-4±12 vs 0.01±10 ms; p=0.09), paralleled by a trend towards a decrease in the variability of the relative timing error (SD) (17±11 vs 12±6 ms; p=0.08). This means that subjects learned to initiate movement later to more successfully hit the targets, and were more homogenous in doing so. No difference was noted when comparing B1 to RC following EA training (-0.9±7 vs -4±12 ms; p=0.2) (between conditions, $t(10)=1.3$, p=0.11) (Figure 2B).

5 DISCUSSION

These preliminary results suggest that as age increases, learning can still occur since the subjects' relative timing error decreased after HG training. This also supports the results of previous studies on the elderly's ability to learn new tasks (Marchal-Crespo et al., 2010).

Moreover, it appears that a robotic assisted hand could be an effective approach in improving elders' timing errors; however, only HG appears to benefit them. This supports the results of our previous study, which was conducted on young healthy individuals (Milot et al., 2010); here, less-skilled subjects did not benefit from EA in the timing-based task (k value < 0.1). It is plausible that for this sub-group of subjects, EA training was too challenging since the motor system was overwhelmed with too much information, preventing any improvement in performance. This could be the case in this current study, since the seniors' mean k value is 0.07 (range: 0.02; 0.1), falling into the less-skilled sub-group category.

This current study is part of an ongoing project, so more subjects are needed in order to validate the preliminary results and to assess the long-term benefits of HG and EA on improving movement timing. If HG and EA trainings are proven to effectively do so, they could potentially help improve the movement timings of neurologically impaired individuals like chronic stroke survivors.

REFERENCES

EMKEN, J. L. et al. 2005. Robot-enhanced motor learning: accelerating internal model formation during locomotion by transient dynamic amplification. *IEEE Trans Neural Syst Rehabil Eng,* 13**,** 33-9.

LUTTGEN, J. et al. 2013. The influence of robotic guidance on different types of motor timing. *J Mot Behav,* 45**,** 249-58.

MARCHAL-CRESPO, L. et al. 2010. The effect of haptic guidance, aging, and initial skill level on motor learning of a steering task. *Exp Brain Res,* 201**,** 209-20.

MARCHAL-CRESPO, L. et al. 2013. The effect of haptic guidance and visual feedback on learning a complex tennis task. *Exp Brain Res,* 231**,** 277-91.

MILOT, M. H. et al. 2010. Comparison of error-amplification and haptic-guidance training techniques for learning of a timing-based motor task by healthy individuals. *Exp Brain Res,* 201**,** 119-31.

PATTON, J. L. et al. 2004. Robot-assisted adaptive training: custom force fields for teaching movement patterns. *IEEE Trans Biomed Eng,* 51**,** 636-46.

SEIDLER, R. D. et al. 2010. Motor control and aging: links to age-related brain structural, functional, and biochemical effects. *Neurosci Biobehav Rev,* 34**,** 721-33.