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The Effect of Aging on Brain Temporal Perception using Virtual Reality Neurocognitive (VRN) Experiments

Mari T. Garcia Campuzano, IEEE Student Member, and Zahra Moussavi, IEEE, Senior Member

Abstract— **This paper reports a study conducted to assess brain temporal perception across different age groups. A novel Virtual Reality Neurocognitive (VRN) test, which consists of catching a virtual bouncing ball with a paddle, was employed. A total of 44 volunteers with no cognitive impairments and 3 individuals diagnosed with depression but cognitively healthy, in the age range of 19 to 82 years, participated in this study. Results show that the ability to accurately perceive time deteriorates with age.**

I. Introduction

Perceiving and processing temporal information is one of the brain's essential features [1]. Precision in time perception is fundamental for success in many life aspects such as recognizing the surrounding environment, learning complex processes, or performing any coordinated motor movement [2,3]. The brain's temporal perception is classified into explicit timing and implicit timing.

Explicit timing is defined as an intended estimation of time with discrete duration, for comparison with an early memorized standard [4]. An example of explicit timing is when one has an appointment with a family doctor: before the appointment a deliberate estimation of the duration of the visit would be made.

Implicit timing, on the contrary, takes place when an emergent temporal prediction is made without any specific quantification of time. When this temporal prediction is associated with motor output tasks, the implicit timing results in a byproduct of motor control dynamics [4]. For instance, implicit timing may be involved during driving, either to prevent a collision with an oncoming vehicle, or after seeing a yellow light when estimation is made about how much time is required to either accelerate or stop the vehicle. Furthermore, in an implicit timing process making a prediction can be conscious (endogenous) or unintentional (exogenous) [4]. In this study, we assess the implicit temporal perception of participants with no sign of any cognitive impairment. We hypothesize that this implicit temporal processing deteriorates with aging.

In a similar study assessing the implicit temporal processing of the brain [5], a 2D falling target game was designed, in which the speed of the falling target (a flower) varied from trial to trial. The task was to catch the target half way through the falling path. The game was played using a robotic arm with 2 degrees of freedom mimicking the forearm of a human subject. The subjects received audio and visual feedback indicating whether they caught the target too fast, on time or too slowly. The experiment was run on three groups of subjects: children (7-12 years), young adults (18-35 years) and elderly (65+ years). The results showed a similar performance in children and elderly, while the performance of both groups was significantly different compared to that of the young adult group [5]. Since the game in [5] was designed such that the right estimated time to catch the target was always when it was in the middle of the screen vertically, it is possible that some people found this pattern intuitively by repetition, and instead of estimating the speed of the target simply aimed for the middle of the screen and waited for the target to fall and be caught. Therefore, this might have affected the results.

In this study we assessed participants' temporal processing using a Virtual Reality Neurocognitive (VRN) test, which provides varying temporal stimuli [5]. The VRN test employed in this study consisted of catching a virtual ball with a paddle through different iterations. During the test the speed of the ball increased in a linear fashion. The exogenous type of temporal perception is described as an alertness factor of the ball's speed change. The game ended when the player could not predict the ball's speed correctly and missed the ball.

The methodology used in this study differs from that of [5] in several ways. The aim of this project was to further investigate temporal perception by including more age ranges. Also, in our VRN test the direction of the ball was changing during the game, while in [5] the direction of the target did not change as mentioned above; therefore it was possible that the young fit adults could go to the middle of the screen very fast and wait for the ball. Having a target with varying direction gives a better assessment of temporal cognition, because the subjects must implicitly calculate the speed that they have to apply to catch the ball. This paper reports the preliminary results of the study.

II. Method

A. VRN Test: "The Falling Ball"

We used our recently designed "Falling Ball" VRN test [6]. Throughout the test the participant is asked to repeatedly catch a virtual bouncing ball using a real paddle, which is manipulated by a PlayStation® 3 (PS3) Move motion

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M. T. Garcia Campuzano is with the Electrical and Computer Engineering Department, University of Manitoba, Winnipeg, MB, R3T 5V6 Canada. (phone: 204-474-9603; fax: 204-261-4639;
e-mail: umgarc36@cc.umanitoba.ca).

Z. Moussavi is also with the Electrical and Computer Engineering Department, University of Manitoba
(e-mail:zahra_moussavi@umanitoba.ca).

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detector. Every time the player catches the ball, the paddle vibrates, the ball's speed increments linearly, and the player receives auditory, visual and haptic (vibratory) feedback. For the participants to be able to hit the ball with the paddle, they have to estimate the ball's speed, which is linearly increasing by 5 pixels/second after each hit (implicit timing processing). A camera is utilized to track the movement of the paddle. The test ends when the player fails to catch the ball. To make the experiment interesting for the participants, it was designed such that by hitting the ball each time, some bricks are removed from the top of the screen (similar to the Brick Ball game). However, the number of broken bricks was not yet analyzed (this number is representative of the player's temporal processing performance).

The Falling Ball test of this study consisted of four trials. Each trial continued until the subject failed to catch the ball. The first three trials were designed with 'normal' physics; this means every time that the ball was caught with the middle of the paddle, the ball bounced off the paddle straight up and bounced back to the paddle following a straight line; if it was caught with the right edge of the paddle, the ball bounced off the paddle towards the right. The fourth trial was designed with 'random' physics, meaning that it did not matter at what edge of the paddle the ball was caught; after each hit the ball bounced off the paddle at a random angle.

For each trial, the maximum speed (the speed at which the game ended) was recorded and analyzed.

B. Subjects

Forty seven individuals (24 males), between 19 - 82 years old with no cognitive impairment participated in this study. The study was approved by the Biomedical Health Ethics Board of the University of Manitoba. All participants signed a consent form prior to the experiments. Three of the participants (2 females of ages 34 and 76, and 1 male, age 21 years old) reported to had been diagnosed with depression.

Prior to the tests, an interview was conducted, in which the participants were asked if they had any experience with video games, if they played any sport in the last one year, and whether they had been diagnosed with any mood disorder. The cognitive level of all participants was assessed by the standard Montreal Cognitive Assessment (MOCA) questionnaire [7], in which a score of greater than 26 out of 30 is considered to be normal.

C. Experimental Protocol

The experiments took place at the Virtual Reality Centre in Winnipeg, Canada. The Falling Ball test was projected on a big screen, while the subject was seated about 3 meters away from the screen (Fig. 1).

All participants played the game for a few minutes to become familiar with the game and learn how to manipulate the controller. Then, the game's control equipment was

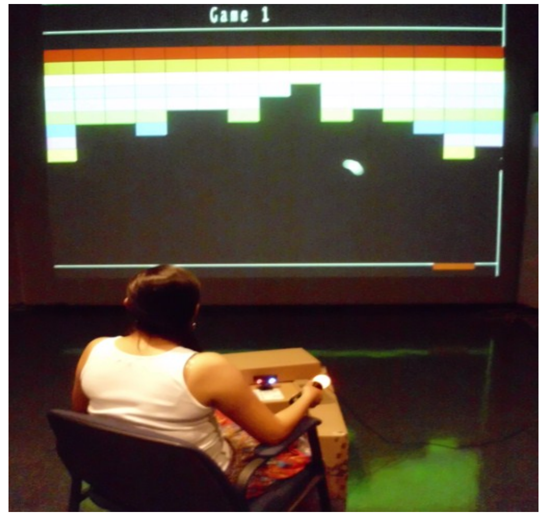

Figure 1. Experimental Setup

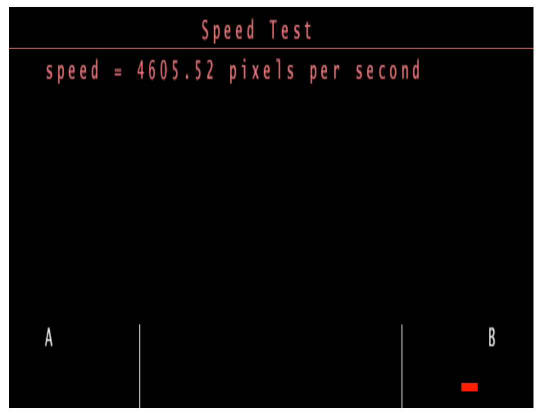

Figure 2. Speed Test Screen

calibrated to ensure that device irregularities did not interfere with the participant's ability to play the game.

After the calibration a 'speed test' was performed before and after the four game trials, where the subjects were asked to make swift horizontal movements with the paddle across the screen (from region A to region B or vice versa) as fast as they could (Fig 2.); this was repeated 6 times and the average speed was recorded. This speed test was done to determine the participant's maximum speed before and after the game trials for three purposes: 1)to ensure there were no problems with the movement tracking across the entire screen, 2) to investigate the effect of fatigue due to playing the games 4 times, and 3) to investigate whether there was any substantial difference in the physical ability of the subjects of different age groups. The average speeds of these swift movements were recorded before and after the 4 trials and compared statistically among the age groups.

As the instructions for the test, the subjects were encouraged to hit the ball as many times as they could. No other information about the ball's speed or its changing pattern was given to the subjects.

C. Data Analysis

From the first three trials, which were designed with 'normal' physics, as well as from the 4^{th} trial which was designed with 'random' physics, the maximum or best speed of each participant was marked and compared between the subjects in different age groups.

The population of this study, excluding the 3 participants with depression, was divided into three different age groups: 19-40, 41-60 and >60 years old. These groups had 22 (15 males), 15 (4 males) and 7 (4 males) subjects, respectively. The maximum speeds of the subjects within each group and in both modes, 'normal' and 'random', were averaged and compared between the groups. The statistical test of Analysis of Variance (ANOVA) was run between the maximum speeds of the subjects in each group to test for any significant differences. The performance of the participants with depression is only shown for visual comparison as their number was too low to run any analyses.

To investigate whether any plausible difference in physical ability between younger and older participants played a role in their ability to estimate the time for catching the bouncing ball, we analyzed the speed during the 'speed test' before and after the 4 trials of the game. .A two tailed t-test was applied on the maximum speeds of the three different age groups (19-40, 41-60 and >60 years old) to test for the existence of a statistically significant difference between them.

III. Results

A. Relationship between Aging and Temporal Performance

The average maximum speeds (±standard error) during the 'normal' physics trials were 455±20, 373±23.3 and 334±26.5 pixels/second for the age ranges of 19-40, 41-60 and >60 years, respectively. A correlation coefficient of -0.55 was obtained. The ANOVA test showed a significant difference (*p*-value=0.0041) between Group 1 (19-40 years old) and Group 3 (> 60 years old).

In the 'random' physics trial, the average maximum speeds (±standard error) were 282±19.3, 296±30.5 and 212±15.8 pixels/second for the three age groups listed above, respectively. In this case the ANOVA test did not show a significant difference between the groups, although a nearly linear trend with aging was still observed (Fig. 3).

Fig 3 illustrates the participants' maximum speed versus their age from the first three trials (the 'normal' physics trials) and the speed during the fourth trial (the 'random' physics trial, marked with a red asterisk). In general the performance during 'random' physics was lower compared with that of 'normal' physics; this can be explained due to the unpredictability of the bouncing ball's direction during 'random' physics.

As can be seen in Fig. 3, there is a linear trend (slope =-3.24) between age and deterioration of temporal processing.

B. 'Speed Test' Results for Before and After the Four Trials

For the age ranges of 19-40, 41-60 and >60 years old a two tailed *t*-test was applied to the averaged maximum speeds of the three groups, before and after the four trials, revealing that there was not a statistically significant difference between the means of these groups. This implies that the physical fitness of the subjects across the age groups was not playing a role in their performance. Also it could be suggested that the participants didn't require previous video game experience to perform well.

IV. Discussion

The brain's temporal processing is known to be an integral part of perception and motion control [1]; thus, it has been studied for different purposes, using different tools and from different perspectives. Our approach attempted to explore the effect of aging on the brain's implicit temporal processing.

During this study eye-hand coordination was an important factor. Eye-hand coordination is defined as a complex neurological process which starts with visual information sent by the eyes to the brain and processed in the cerebellum. The cerebellum controls the motor timing coordination [8].

Eye-hand coordination decreases with age either due to joint stiffness or to a decline in temporal perception [9]. The similarity of the means between groups (during the 'speed test') implies that joint stiffness was not a factor in our VRN test; therefore, the observed difference associated with aging must be due to a change in implicit temporal perception.

The results of this study are congruent with a previous study [5], in which the temporal processing of the subjects was assessed by a 2D falling target computer game played using a robotic arm. That study also found significant differences between the performances of people between 18-35 years old compared to those of 65+ years old healthy participants. The age span of Group 1 of our study is similar to the young adult group of the study in [5].

In the previous study [5], as mentioned before, the direction of the falling object was always the same; thus, one may question if that would have affected the results. In this study the direction of the ball changed during the game. We also tested when the direction of the falling ball could be anticipated and when it was unpredictable. The results show that in both conditions, temporal processing cognition deteriorates with age.

One of the advantages of this study compared to that in [5] is that the design of this game in virtual reality provided a naturalistic environment. The paddle vibrated every time that it hit the virtual ball, providing an experience similar to using a racquet to hit a real ball.

Three of our participants were diagnosed with depression. Despite having no cognitive impairment, it is interesting to note that their performance was much below the average of their age group (they are marked by the circles on Fig. 3). This observation is congruent with previous findings [10, 11], where researchers reported that the ability of depressed people to perceive time is decreased since their internal clock gets slower . However, we acknowledge that our data is insufficient to draw any conclusion. We did not actively recruit people with depression.

Overall the results are encouraging and suggest that the designed Falling Ball test is useful to effectively assess the temporal processing of the brain. Futhermore the experiment was described as being fun and engaging by many of the participants. The results of the depressed people's performance, although limited, are also interesting. The number of depressed participants was too low to draw any conclusion; however, as the results are logical given the physiology of the brain changes due to depression, the results are encouraging for further research, to study the plausible use of such tests as a clinical tool to aid diagnosis of depression.

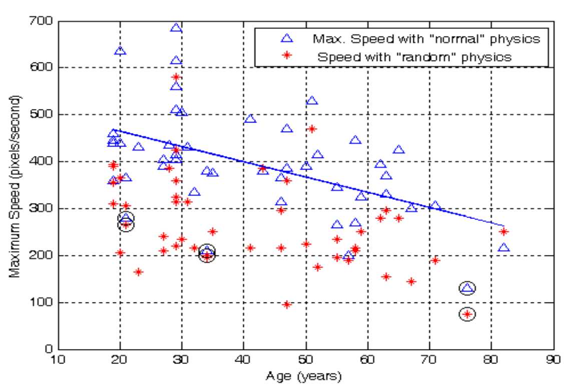

Figure 3. Healthy control group's Maximum Speed during trials with 'normal' and 'random' physics; data of depressed participants are marked by a circle around the marker.
(population = 47 participants)

V. ACKNOWLEDGMENT

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