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Human Brain Performance in Learning Complex Temporal Patterns

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Abstract— **This paper presents the experiments investigating the healthy adult human brain performance on motor tasks with simple and complex temporal patterns. A 2DOF manipulandum and a set of interactive computer games were used in this study. The games consist of a falling target that should be caught under different temporal constraints that change in every new trial by a change in the target's falling rate. Target's falling rate pattern included: linearly incremental, 2nd order polynomial and random. These patterns were tested on 10 healthy adult subjects and the outcomes were compared with respect to their association with the actual falling target's pattern. Results show the best and the worst observed performances to belong to linearly incremental and random games, respectively.**

I. Introduction

Accurate temporal and spatial perception is an important factor toward successful performance of any motor task (e.g. arm movement). Brain temporal performance is defined under two broad categories of explicit and implicit timing. Explicit timing is a deliberate temporal expectation for discrete events, while implicit timing is when a sudden temporal prediction is built without any specific instruction to time [1]. The primary goal for temporal expectation is to optimize the motor performance where the temporal perception is either formed by the subject's expectations using the informative pre-cues, or it is incidentally built as a by-product of ongoing motor action. Therefore, temporal perception can be subconscious and unintentional (exogenous), or conscious and deliberate (endogenous) [2].

In this study, we analyzed the temporal perception by studying the subjects' performance encountering a stimulus with varying temporal dimension. For this, we used a set of interactive computer games to catch a falling target with variable falling velocity. Considering the implicit and the explicit timing definitions, the temporal perception formed during playing the falling target game would be of type implicit timing, while the exogenous or endogenous type of this temporal perception is a factor of subject's awareness about the changes in the successive cues. In general, inability to learn and accommodate to the changes in the falling rate appears in the form of not noticing the duration of an event that results in missing to catch the target.

For any goal oriented motor action, in order to achieve the optimal performance, the maximum-velocity (V_{max}) and time for the movement should be correctly estimated. Therefore, we investigated the subjects' arm movement velocity and time profiles plus their trends of change to follow the change in the target's falling rate.

We hypothesize the performance in adapting to a linear pattern of change is significantly better than that to a complex pattern. Furthermore, the performance improves if the subject can approximate the nonlinear pattern using a combination of linear patterns.

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II. Method

A. Manipulandum

The robotic arm (manipulandum) used in this study is a 2DOF parallel four-bar linkage with two drive motors mounted at the base [3]. The manipulandum consists of two segments representing human arm and forearm in a 2D plane. The first segment is connected to the base and rotates around an axis parallel to the base representing the shoulder joint, and the second segment is connected to the other end of the first segment and rotates around an axis representing the elbow joint. Subjects were instructed to play the game using the manipulandum, through which the movement trajectories and their velocity were measured and recorded.

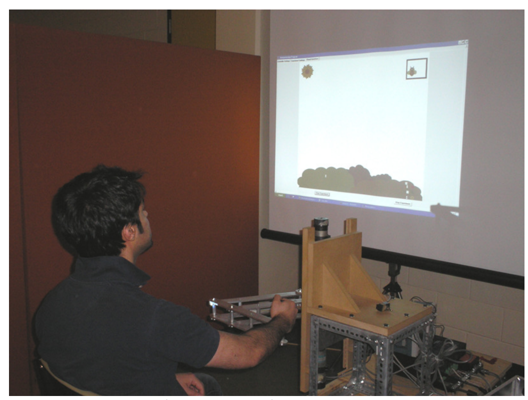

Fig. 1. Experiment Setup.

B. The Falling Target Game

The interactive computer game developed for this study is catching a falling target (a flower) with moving the cursor (a honey bee) by an appropriate velocity to reach the target before it touches the ground (Fig. 1). The starting location for the subject is a fixed location (the top right corner of the screen indicated with a black square) throughout the game. The subject must move the bee to its starting location at the beginning of the game and after each trial in order to start a new trial. In every new trial, when the cursor is remained inside the start square for 400 ms, a "GO!" message appears on the game screen and the target starts to fall.

To test the brain temporal performance and its adaptability to different patterns, the velocity of the falling target was designed based on the following patterns:

1) *Linearly incremental change;*
2) *A 2nd order polynomial;*
3) *Uniformly distributed random function.*

Note that the velocity of the target in each trial was fixed but changed from trial to trial.

During the games, subjects received visual and auditory feedbacks on their performance. We set three time thresholds: the target's color turned to red if the subject caught the target at a time less than or equal to the first threshold, to green if the subject met the second threshold, and to yellow if the second threshold was passed. The thresholds were adjusted in each trial with respect to the target's falling rate. These thresholds satisfy the lower bound of ~ 220 ms reaction time reported in [4]. This lower bound corresponds to the time required to detect and discriminate the visual stimulus and then to execute the motor action.

On the other hand, an auditory feedback indicating the success trial (when catching the target in green color) and another indicating the failure trial were added as another type of performance feedback. In order to make the game more attractive and drive subject's motivation to continue the game attentively, a score bar was also added to the bottom right corner of the screen showing three numbers with a flower beside each number. Each one of the flowers represented a timing constrain indicated with different colors (red, green and yellow), and carried the subject's score in catching the target under those timing thresholds.

The subjects were only instructed to try to catch the target such that the target's color turn to green; in other words to maximize their Green score. Therefore, the Green flower score was used as a measure of subjects' performance.

C. Experiments

The above mentioned patterns of the falling target's velocity were used in a set of three experiments on 10 young subjects (26.6 ± 3.1, 5 females). Each subject played the games with the three falling rate patterns for 120 trials in each game, and his/her performance was recorded in the form of XY trajectories and velocities for further analysis.

Ethics approval was granted prior to recruiting participants by The University of Manitoba, Faculty of Medicine, Research Ethics Board.

D. Data Analysis

In reaching movement studies, it has been shown that the subjects' trajectory after adaptation become close to a straight line between the starting and target points with a single bell-shaped velocity profile spread out on the trajectory's time interval [5], [6]. Hence, analyzing the velocity profile of the subjects in the three experiments of this study should reveal the nature of learning and adaptation to the temporal pattern of change.

To maximize the Green score in the three games, one must predict the target's falling velocity, and adjust his/her hand's velocity in order to catch the target on time. In a perfectly predictable scenario the subject's velocity change will follow the actual target's falling velocity closely.

The amplitude of the V_{max} in each trial and its corresponding time were measured and averaged over bins of 8 trials for the total number of 15 bins, which covers all the 120 trials in each game. This is done to see the trend of change in the V_{max} amplitude and its occurrence time in comparison with the corresponding actual pattern of the falling target's velocity.

As a measure of performance in the case of linear pattern of falling rate, the difference between the slopes of the actual falling rate and the fitted line to the averaged V_{max} amplitude trend was used. To measure the performance in the polynomial games, the following parameters were considered:

- *Rate Of Change (ROC) in the two sides of the averaged V_{max} amplitude and time trend parabolas,*
- *The bin where the extrema points in the averaged V_{max} and its corresponding time trend occur.*

These parameters were calculated and compared for the averaged V_{max} and its corresponding time trend in the polynomial games.

The Mean Square Error (MSE) (Eq. 1) along with the Standard Error (SE) between the actual signals and the observed ones for the averaged V_{max} amplitude and its corresponding time trend was calculated for all the games (linear, polynomial, and random).

$$MSE = \frac{\left(\sum_{j=1}^{15}\left(x_{ij} - x_{oj}\right)^2\right)}{n}, \quad (1)$$

Where x_{ij}, x_{oj}, and n represent the points along the actual signal, the points along the observed signal and the total number of bins (15), respectively.

In addition, the difference in the amplitude at the minimum of the actual V_{max} trend and that of the observed one was used as the measure for the time perception error in the case of polynomial games.

The statistical student *t*-test was used to investigate any significant difference between the MSE of the V_{max} amplitude, the V_{max} occurrence time and the subjects' Green scores between the games with different falling target's velocities. In all instances, the *p*-value was set at 0.05.

III. Results and Discussion

Figure 2 (a-c) shows the 2D representation of the V_{max} amplitude (shown by a color code) versus its occurrence time for a typical subject playing the linear, polynomial and random games, respectively.

The V_{max} occurrence time trend throughout the 120 trials inversely follows the linear and polynomial patterns of change in figures 2a and 2b. On the other hand, Fig. 2c doesn't show any deterministic pattern; this was expected as the game with random falling rate was supposed to be unpredictable.

Figures 3 to 5 illustrate the averaged V_{max} and its corresponding time trend for linear incremental, polynomial and random games, respectively. The slope difference between the actual V_{max} and the observed one in the linear game was found to be 0.006, implying that the subjects were able to estimate the target's falling velocity pattern closely.

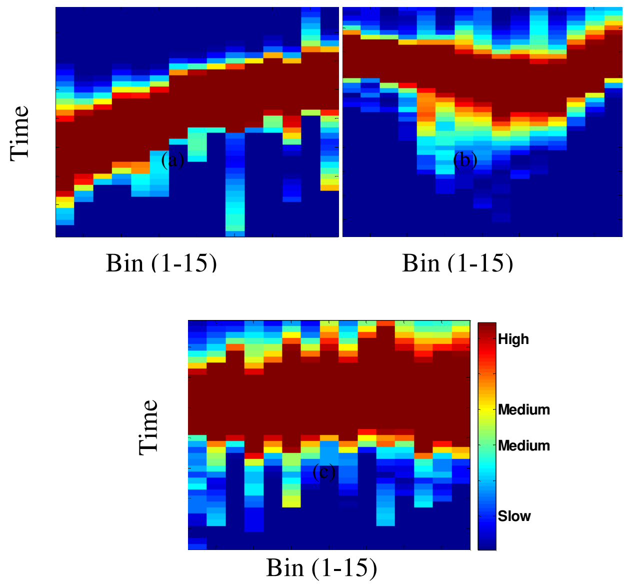

Fig. 2. V_{max} occurance for a typical subject through the a) linear, b) polynomial, and c) random games, respectively.

In figure 4, the parabolas are left skewed resulting in an asymmetric shape which is also the case in Fig. 2b. It was observed that the minimum of the averaged V_{max} amplitude and the maximum of its corresponding time occur in the bin 9 which is to the right of the bin containing these extrema points in the corresponding actual V_{max} trends (bin 8). On the other hand, the calculated values for the ROC of the first and second sides of the parabolas in Fig. 4(a-b) are 0.11, 0.172 and 0.127, 0.162, respectively.

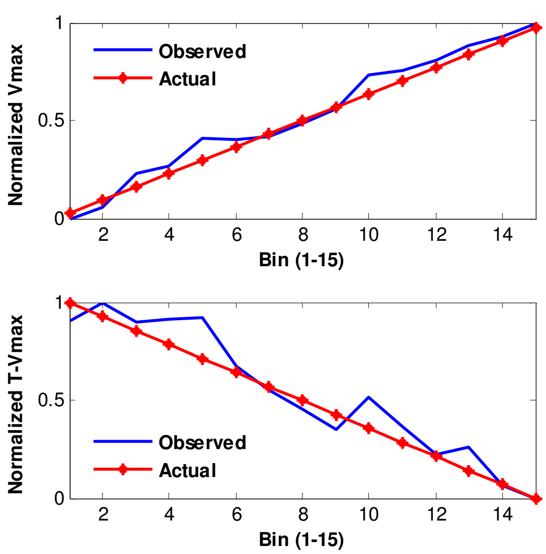

Fig. 3. Linear V_{max} and V_{max} corresponding time (T- V_{max}) trends, respectively.

As can be seen, the ROC values are relatively higher for the second side of the averaged V_{max} amplitude and time trends. This is due to the higher variations observed in the trend of subjects' hand velocity happening in the second half of the trials (i.e. trails 60–120) to follow the target's velocity.

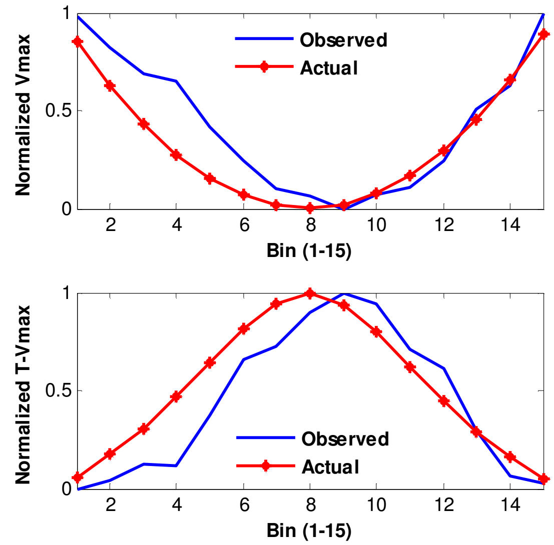

Fig.4 . Polynomial V_{max} and V_{max} corresponding time (T- V_{max}) trends, respectively.

The MSE values along with the SE for all the games are shown in Table. I.

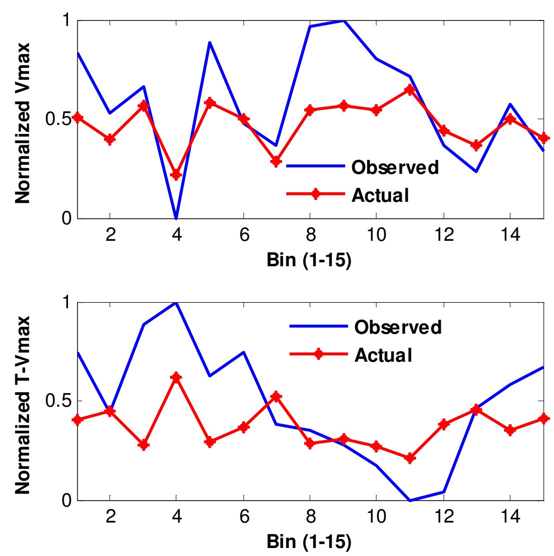

Fig.5 . Random V_{max} and V_{max} corresponding time (T- V_{max}) trends, respectively.

TABLE. I
MSE AND SE OF VMAX AND ITS CORRESPONDING TIME TRENDS IN DIFFERENT GAMES.

Game	MSE Vmax	MSE Time
Linear	0.023±0.003	0.049±0.007
Polynomial	0.033±0.00	0.061±0.006
Random	0.069±0.048	0.092±0.057

As can be seen, the errors are relatively higher for the random game than the other two games, implying poor performance in estimating the target's velocity with random pattern of change as expected.

Table II shows the probabilities that the null hypothesis (i.e. performance difference is due to the chance) should be accepted between each pair of data groups, and whether these probabilities are significant with 95% confidence interval. The results of Tables I and II along with those depicted in Fig. 5 show that no learning occurred in the case of random game.

TABLE. II
THE *P*-VALUES OBTAINED BY STUDENT *T*-TEST BETWEEN THE MSE VALUES AND THE GREEN SCORES OF DIFFERENT GAMES. THE * INDICATES THE SIGNIFICANCE OF THE TEST.

	MSE		Score
Test	Vmax	Vmax time	Green
Linear-Polynomial	0.3375	0.4856	0.1173
Linear-Random	0.0001 *	0.0075 *	0.0000 *
Polynomial-Random	0.0066 *	0.0278 *	0.0011 *

The Green scores averaged over 10 subjects for the linear, polynomial and random games were 99.5, 87.5, and 60.5, which show degrading in performance as the pattern of change becomes more complex in terms of linearity.

The results of this study congruently prove our hypotheses that a novice user can predict a linear pattern much better than complex ones and also perform reasonably well as long as the function (i.e. a polynomial) can be estimated by a piece-wise linear function.

Furthermore, the time perception error for the polynomial game was found to be equal to 0.0540, which corresponds to the 5.4% difference of the maximum value. As mentioned earlier, this study was done on healthy adults in age range of 21-31years. We hypothesize this parameter would be significantly different in elderly and patients with dementia; hence, it may be used as an objective measure of mental disorder's of patients at early stages.

IV. CONCLUSION

Through this study the brain capability in predicting the temporal profile of different patterns of change was tested. We hypnotized that the brain is more efficient in predicting those patterns which can be approximated by linear or piece-wise linear functions (i.e. a polynomial is approximated by two lines in its two tails). The results confirm this hypothesis. In addition, the results show some commonalities in the subjects' performance encountering different patterns of change such as the skewness of the actual (predicted) performance to the right in the case of polynomial games. It is reported that the patients with deficiencies in cerebellum and fronto-striatal circuits have problem in temporal perception which is considered as an early symptom of dementia [7], [8]. Therefore, the temporal perception error parameter of this study may be used as an objective test for early diagnosis of dementia.

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