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Eye-Hand Coordination during Self-Moved Target Guiding Along Labyrinth Path

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Introduction

Human behavior in manual control coordinated by vision illustrates perfect synchronization between the gaze and position of the target, which is controlled by hand. Investigation of eye-hand coordination is useful for alternative control of computer cursor [1] and for an assessment and rehabilitation of a sensorimotor system of patients [2].

In the previous study we investigated eye-hand coordination during tracking the target, which moves along two-dimensional non-predictable trajectory with three different average target speeds [3]. We found that precision of the ocular-motor pursuit drops down for 10-20% during oculo-manual pursuit. This means that, when hand is free from the action of manual control, the gaze is able to pursue the target more accurate. Also we found that during oculo-manual pursuit the target-eye (T-E) precision is higher than target-hand (T-H) precision. Using artificial shifts in time between the trajectories of target (T), eye (E) - gaze and hand (H) we found critical values of the shifts at which T-E errors and T-H errors got the smallest values as shown in Fig. 1. Obtained critical values of shifts in time L_{TE}= 0.06 s and L_{TH}= 0.04 s could be interpreted as the tracking delays.

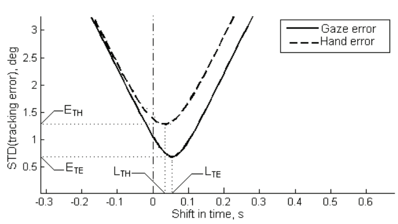

Fig. 1. STD of tracking errors between target and hand and between target and eye (gaze) trajectories as a functions of artificial shifts in time

Taking in account modeling results of neural networks of the control systems of eye and hand motion (time delay for hand is 0.41 s and for eye – 0.02 s, time constants for hand is 0.048 s and for eye – 0.018 s [4]), we can resume that hand motion predicts target trajectory better than eye. For example, as seen in Fig. 2, the average tracking delays between T-H for target speed 10 deg/s is negligible small. A few subjects during manual pursuit illustrated not the delay but an anticipation of the future target trajectory.

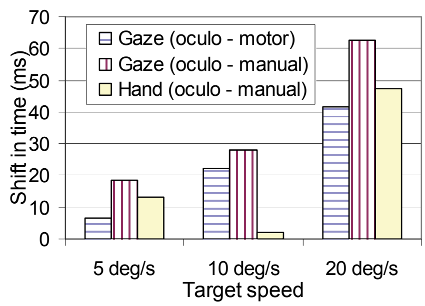

Fig. 2. Tracking delays between the T-E and T-H trajectories as a function of target speed obtained during oculo-motor and oculo-manual target pursuit

In the present series of experiments, eye-hand coordination, during execution of two different oculo-manual tasks: target guiding through a pre-set environment and target guiding in an empty space, was investigated. Depending on tracking parameters, two eye-hand coordination strategies were observed.

Method

Six subjects were asked to move the target (cursor) along the labyrinth's path (LP) quickly enough. The shapes and complexity of labyrinths used in LP experiments are shown in Fig. 3. The same self-moved target experiments were repeated in the situation when subjects had to draw the labyrinths (LD) close to those, which were used in LP experiments.

During all experiments, movements of both eyes were recorded with eye tracker “EyeGaze System” produced by “LC Technologies Ltd.” Gaze tracking instrumentation was setup so, that to 1 deg eye angle corresponds to 46 pixels on computer screen. Absolute hand position, reported by tablet WACOM “Intuos 2”, was also registered and retained for further processing. Healthy subjects, 21-48 years old, were recruited after informed consent. Among the six subjects, two authors participated in the experiments. None of the subjects showed any visual, oculo-motor or oculo-manual pathology. Subjects had normal visual acuity without glasses.

Two-dimensional trajectories of hand and gaze were recorded and distance between self-moved target and gaze were calculated and analyzed for each data sample. Also the delays between the self-moved-target and gaze were analyzed by shifting gaze and hand trajectories in time with the purpose to find the critical value at which STD between T(H)-E became minimal.

All calculations were processed using standard MATLAB functions.

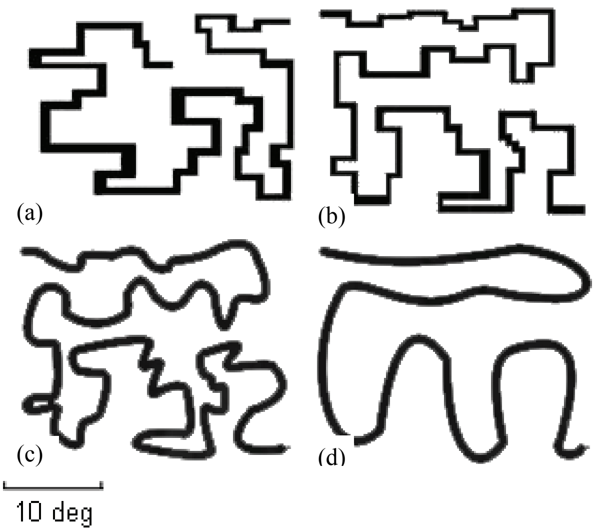

Fig. 3. Shapes of labyrinths (a), (b), (c) and (d) used in LP and LD experiments

Experimental results

The segments of the trajectories of self-moved target, gaze and difference between them in the horizontal and vertical coordinates are shown in Fig. 4. Experimental results plotted in Fig. 4 illustrate the strategy of eye-hand coordination during LP task. At time t_1, gaze elicited a jump (amplitude around 1-2 deg) along the horizontal path of labyrinth with the purpose to asses visually the future path for the hand. During time interval t_1 to t_2 self-moved target was moved by hand closer to the gaze position, which remained unchanged. At time t_2, the distance between gaze and self-moved target became small (in the range of 0-0.5 deg) and gaze elicited second jump. Third gaze jump was elicited at time t_3 and coordinated motion in the horizontal direction was accomplished at time t_4. At the same moment, due to changed direction of labyrinth path, gaze elicited jump in the vertical direction. During time interval from t_4 to t_5 self-moved target was moved closer to the location of gaze position. Described behavior of eye-hand coordination is based on gaze jumps (GJ) along the trajectory path and could be called GJ strategy.

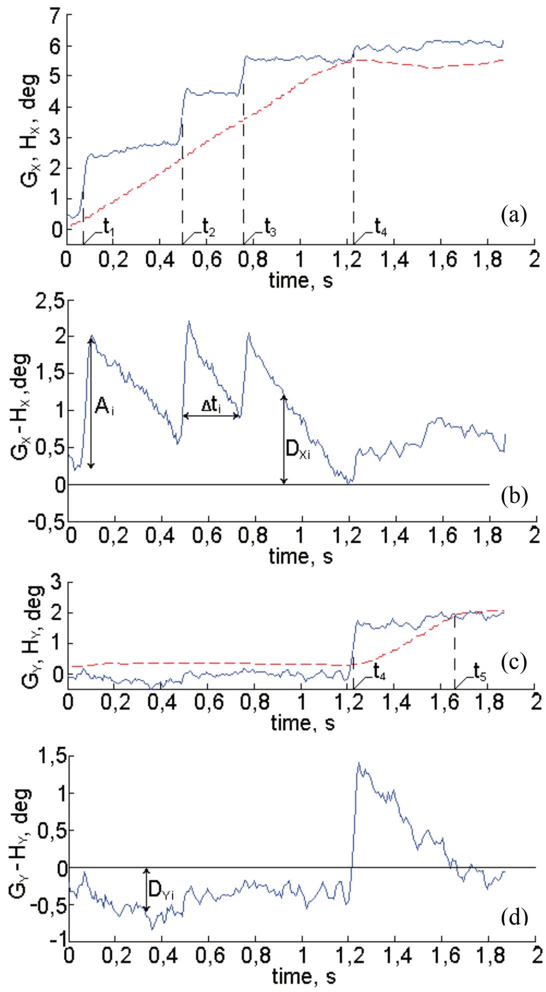

Fig. 4. Presentation of pieces of the trajectories for Gaze jumps (GJ) strategy (a, c): self-moved target (dashed line), gaze (solid line) and difference between them in the horizontal (b) and vertical (d) coordinates

Contrary to that, in Fig. 5 presented experimental data illustrates scenario without strongly expressed gaze jumps and fixations. Gaze in this situation was moving smoothly and congruently with the self-moved target. This strategy could be called Gaze Moves Smoothly (GMS) strategy. Main difference between GJ and GMS strategies depends on the role of vision. In the GJ strategy, main task of vision is the supply of future path information for manual tracking process. During GMS strategy gaze is focused not on the path to be passed but on the self-moved target. This is clear because eye is not able to execute smooth pursuit or to move smoothly without target to be tracked [5]. Also it must be evaluated that vision is not concentrated only on the point of fixation but is able to change attention in the wider visual field. Therefore GJ and GMS strategies could not be so clearly distinguished in the tracking process and could be quickly changed. To evaluate how much these eye-hand coordination strategies are common and differs for all six subjects during LP experiments we calculated and analyzed means and standard deviation (STD) of these tracking parameters: amplitudes of gaze jumps A, number of gaze jumps N during all tracking time T, time intervals between two jumps Δt, self-moved target velocity V, distances between eye and target D_X, and D_Y in the horizontal and vertical coordinates. Majority of these parameters are illustrated in Fig. 4.

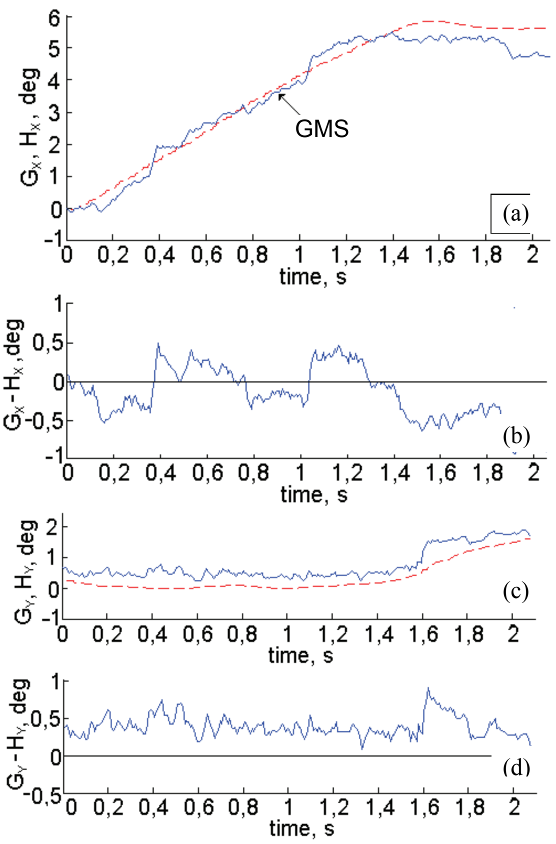

Fig. 5. Presentation of pieces of the trajectories for GMS strategy (a, c): self-moved target (dashed line), gaze (solid line) and difference between them in the horizontal (b) and vertical (d) coordinates

Tracking parameters of different subjects, obtained using two different eye-hand coordination strategies (GJ and GMS), and average of these parameters for all six subjects are placed in Table 1. STD values are given in brackets.

Table 1. Parameters obtained during guiding self-moved target along labyrinth path

Subj. (strat.)	N	A, deg	Δt, s	V, deg/s	T, s	D_x, deg	D_y, deg
SN (GJ)	68	0.71 (0.4)	0.34 (0.2)	8.1 (3.2)	25	0.55 (1.0)	0.38 (0.7)
RZ (GMS)	51	0.56 (0.2)	0.68 (0.6)	5.9 (4.6)	38	0.23 (0.5)	0.27 (0.5)
Aver.	54	0.6 (0.3)	0.56 (0.5)	6.9 (4.8)	32	0.38 (0.7)	0.37 (0.7)

As seen in Table 1, during GJ strategy, eye performed the largest number of gaze jumps (68) with the largest average amplitudes (0.71 deg) and average frequency of execution – 2.7 jumps/s. Contrary, during GMS strategy, number of jumps is only 51, average amplitudes 0.6 deg and frequency – 1.3 jumps/s. However the most important difference between these two strategies is overall tracking time T, which is 1.5 longer for GMS strategy. Therefore, it must be summarized that GJ strategy is more efficient. If we give attention to the average of the parameters got for all subjects and placed in Table 1, we can resume that both strategies are equally used by the subjects. Analyzing personal data of each subject, we can conclude that there is some regularity between tracking parameters. The more and the bigger amplitude gaze jumps there are, the smaller the time intervals between jumps and the shorter overall tracking time.

With the purpose to evaluate how much tracking strategies and parameters changes using labyrinths witch contains different complexity (a, b, c, and d in Fig. 3) manual tracking experiments were repeated with all six subjects. Obtained and averaged results are placed in Table 2 and indicate that amplitudes of gaze jumps A and distances between gaze and target D_X, D_Y for all types of trajectories had close values. This means that eye-hand coordination behavior did not depend upon L path complexity. Nevertheless, the most complicate trajectories b and c required longer tracking time T and more gaze jumps N. Tracking velocity V and time interval Δt had the largest values for less complicate path c.

Table 2. Tracking parameters obtained during guiding self-moved target along labyrinth paths with different complexity

Traj.	N	A, deg	Δt, s	V, deg/s	T, s	D_x, deg	D_y, deg
a	54	0.6 (0.2)	0.56 (0.6)	6.9 (4.8)	32	0.38 (0.7)	0.37 (0.7)
b	72	0.62 (0.3)	0.48 (0.5)	7.0 (4.6)	34	0.38 (0.7)	0.36 (0.7)
c	86	0.62 (0.3)	0.38 (0.3)	7.2 (5.2)	33	0.39 (0.7)	0.39 (0.7)
d	56	0.71 (0.4)	0.59 (0.6)	7.8 (4.5)	21	0.4 (0.8)	0.34 (0.8)

Evaluation, how eye-hand coordination depend upon subjects decision to track the path slow but more accurate or more fast but less accurate, was performed by subject SN tracking labyrinth path d. Obtained tracking parameters were placed in Table 3. They illustrate that execution time for slow tracking was 2.5 times larger but required 2.8 times less gaze jumps. Other parameters confirm that slow tracking increases parameters witch represent GMS strategy and, contrary to that, fast tracking increases parameters witch represent GJ strategy (large number eye jumps with big amplitudes and large distances between gaze and target).

Table 3. Tracking parameters obtained during fast and slow manual guiding of self-moved target along labyrinth d

Subj. (strat.)	N	A, deg	Δt, s	V, deg/s	T, s	D_x, deg	D_y, deg
SN (Fast)	53	0.92 (0.5)	0.3 (0.2)	8.4 (6.2)	17	0.92 (1.1)	0.67 (0.8)
SN (Slow)	19	0.47 (0.1)	1.8 (2.2)	6.6 (4.7)	42	0.10 (0.3)	0.11 (0.5)

LD experimental results are placed in the Table 4. They illustrate that during drawing labyrinth (close to b and d in Fig. 3) subjects executed a performance of pursuing by gaze the motion of self-moved target.

Table 4. Tracking parameters obtained during labyrinth draw experiment

Traj.	N	A, deg	Δt, s	V, deg/s	T, s	D_x, deg	D_y, deg
close to b	55	0.52 (0.2)	0.51 (0.5)	7.6 (4.4)	28	-0.29 (0.5)	-0.37 (0.6)
close to d	73	0.6 (0.3)	0.49 (0.6)	7.3 (4.2)	28	-0.16 (0.5)	-0.17 (0.6)

Main difference between LP and LD behavior was negative values of distances between gaze and self-moved target D_X and D_Y. Other tracking parameters in the Table 2 (b and d) and Table 4 did not differ substantially. This means that during drawing new path eye-hand coordination strategy is the same as GMS in the LP behavior. Nevertheless in this situation, gaze was not leading manual action but was lagging in the range of 0.3-0.15 deg.

Conclusions

Investigation of eye-hand coordination during oculo-manual pursuit of moving target, guiding self-moved target along labyrinth path and drawing a new path revealed different behavior of vision.

During oculo-manual pursuit of moving target hand motion anticipate future target trajectory better than eye, however gaze demonstrate better tracking precision. Nevertheless, both gaze and hand are lagging behind the target. Lag of the hand is smaller, but deviates more than the lag of the gaze.

During self-moved target guiding along labyrinth path, the gaze is moving ahead the target supplying the hand motion control system with information about future path.

Two eye-hand coordination strategies Gaze Jumps (GJ) and Gaze Moves Smoothly (GMS) during guiding self-moved target along labyrinth path can be defined. During GJ strategy gaze elicit eye jumps in the direction of the future path. Average amplitude of the jumps is around 0.6 deg and frequency is in the 2-4 Hz range. During GMS strategy gaze is concentrated on the self-moved target and leads it only by small average distance (0.1-0.2 deg).

Difficulty of the trajectory of labyrinth influences amplitudes of jumps and their frequency (for GJ strategy). However, this variable has no substantial impact for how subject behaves: weather uses GJ or GMS strategy.

Subjects tend to shift their strategy from GMS to GJ, as the speed of hand motion increases (and vice versa).

Eye-hand coordination during labyrinth path drawing was the most simple: gaze followed the target, which was self-moved by hand, lagging in the range of 0.3-0.15 deg.

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In this research eye-hand coordination during an oculo-manual tracking was investigated. In the first set of experiments, subjects were asked to elicit guiding a self-moved target (cursor) along labyrinth paths presented on the computer screen. Four various labyrinth paths with different complexity were used. Trajectories of the target, gaze and difference between them were recorded and tracking parameters were analyzed. Two different tracking strategies: Gaze Jumps (GJ) and Gaze moves smoothly (GMS) were defined. During GJ strategy gaze was focused on the future path and during GMS strategy eye tracked a target, which was self-moved by hand. In the second set of experiments, subjects were asked to draw labyrinths (LD) close to those used in the first experiments. During LD experiments gaze was always moving behind hand following target which was self-moved by hand. Ill. 5, bibl. 5, tabl. 4 (in English; abstracts in English and Lithuanian).

S. Niauronis, V. Laurutis, R. Zemblys. Akių ir rankos koordinacijos, labirinto trajektorija vedant ranka valdomą taikinį, tyrimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2011. – Nr. 10(116). – P. 71–74.

Aanalizuojami akies ir rankos koordinuoti judesiai sekant taikinį ranka ir žvilgsniu. Pirmoje eksperimentų serijoje tiriamieji turėjo vesti taikinį (žymeklį) labirinto, pateikto kompiuterio ekrane, trajektorija. Tyrimai buvo atliekami su keturiomis įvairaus sudėtingumo labirintų trajektorijomis. Buvo registruojamos taikinio, žvilgsnio padėties ekrane bei skirtumo tarp jų trajektorijų koordinatės ir analizuojami sekimo parametrai. Buvo nustatytos dvi skirtingos sekimo strategijos: žvilgsnio šuolių (GJ) ir žvilgsnio tolygaus judėjimo (GMS). GJ strategijos metu žvilgsnis sukoncentruotas į priekyje esančią trajektoriją, o GMS metu žvilgsnis yra nukreiptas į ranka vedamą taikinį. Kitoje eksperimentų serijoje tiriamieji turėjo kompiuterio ekrane nubraižyti labirintų trajektorijas, panašias į tas, kurios buvo naudotos pirmame eksperimente. Labirintų piešimo metu žvilgsnis tolygiai sekė rankos trajektoriją nedaug atsilikdamas nuo jos. Il. 5, bibl. 5, lent. 4 (anglų kalba; santraukos anglų ir lietuvių k.).