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Prediction of Target Motion Drives Oculomotor Response during Target Occlusions

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***Abstract*—Prediction of object motion allows overcoming of object occlusions in its trajectory. In this study pseudorandom target trajectory with occlusions of 500 ms was used. It was found that for a period up to 200 ms after target occlusion, oculomotor system was driven by a short-term memory of the pre-occlusion target motion trajectory. We conclude, that when visual system is no longer able to predict location of occluded target, there is a tendency to shift gaze away from previous target location, similarly, away from the edges of the screen. We suggest that this is due to probability, accumulated in long-term memory, which supports expectation that the target should reappear near the centre of the screen. This behaviour supports basic principles of Bayesian decision theory.**

***Index Terms*—Eye movements, smooth pursuit, prediction, Bayes decision theory.**

I. INTRODUCTION

In the complex scenes, moving targets are often occluded by other objects. In the absence of retinal information only prediction of object motion allows to track the target and overcome occlusions in its trajectory. It is known that oculomotor system is able to predict both position and velocity of occluded target for several hundred milliseconds [[1]]. After this period of time velocity of the eye starts exponentially decay to zero when the target is not expected to appear or it reaches a plateau value, when it is expected to reappear.

A lot of research has been done studying predictive mechanisms driving smooth pursuit and saccadic response during target occlusions. However in these studies one-dimensional or two-dimensional predictable target trajectories were used. It was found that pre-occlusion target velocity information determines plateau value to witch eye velocity decays. Providing post-occlusion information showed that eye velocity at target reappearance was only influenced by expected target velocity [[2]]. To minimize the influence of pre- and post-occlusion target velocity information, uniformly accelerated motion, or randomized duration of the blanking periods were used in further studies [[3]], though predictable target trajectories were used. It was suggested that tracking of both visible and invisible predictable targets is influenced by dynamic internal representation of target motion in short-term memory [[1]].

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In previous research [[4]] it was suggested, that when oculomotor system is no longer able to predict location of occluded target, i.e. 200 ms after occlusion onset, gaze is directed towards screen centre, expecting it to reappear there. We suggested that this is due to fact, that target is expected to reappear near the centre of the screen and this supports basic principles of the Bayesian decision theory which defines how new information should be combined with prior beliefs and how information from different modalities should be integrated [5]. However in previous research we used occlusions of 1000 ms that appeared in the peaks of target velocity and their parameters (velocity and angular rotation before occlusion) were more or less the same. During these occlusions participants were able to execute two or three voluntary saccades directing their gaze towards expected target location, i.e. centre of the screen.

In this study pseudorandom time-continuous target trajectory with occlusions of 500 ms was used. It was found that for a period up to 200 ms after target occlusion, oculomotor system was able to predict this pseudorandom target motion. Position errors before the occlusion and up to 200 ms after the occlusion onset depend only on target velocity before the occlusion. After this period of time, prediction of target position is influenced by the probability of the position of target reappearance accumulated in long-term memory.

II. METHOD

Five human subjects participated in experiment. All of them had normal vision and did not have any known oculomotor abnormality. Subjects were asked to track visual target (0.25 deg diameter green spot) moving in pseudorandom trajectory (0). Eyesight position was recorded using LC Technologies EyeGaze System that reports gaze points of both eyes at 60 Hz each, and storied in computer memory for offline analysis.

Target trajectory was presented on the computer screen (resolution 1280*1024 pixels) which was positioned at a distance of 70cm in front of the subject. Overall amplitudes of the target movement were 20 deg in the horizontal and vertical directions. Thirteen occlusions of 500 ms after 1500 ms of visible target motion were introduced in target trajectory. With the purpose not to overlay the occlusions, the same trajectory was repeated for 2 trials with occlusions in different locations. Subjects repeated experiment for 10 times, to get consistent data.

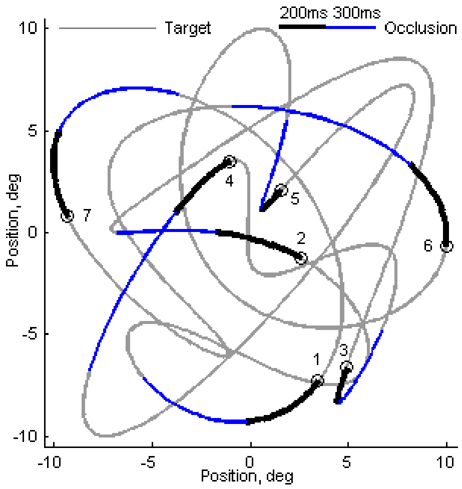

Fig. 1. Target trajectory with marked occlusions. Thin grey line represents visible target trajectory and black thick line – occlusion of 500 ms. Burble and occlusion number denotes onset.

All occlusions were divided into three separate groups according to the target velocity and its angular rotation before the occlusion (0).

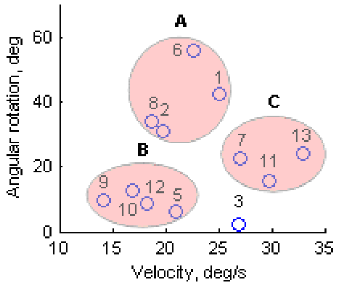

Fig. 2. Angular rotation of the target before occlusion onset with the respect of target velocity before the occlusion onset and division into groups. Occlusion No. 3 and No. 4 (not visible, velocity – 8.4 deg/s, angular rotation – 101.7 deg) are not assigned to any group.

III. RESULTS

Position errors between target and eyesight trajectories at occlusion *onset - 250 ms* to *offset + 500 ms* (step of 50 ms) were calculated and used for further analysis. In 0 position errors at the onset of the occlusion (E1), *onset + 200* ms (E2) and at the offset of the occlusion (E3) are marked by thin grey line ending with the burbles.

As one can see, up to 200 ms (0, red line) oculomotor system is predicting trajectory of the occluded target; therefore a position error does not increase. Oculomotor system is even able to execute catch-up saccade (0, S1) to the predicted target location. After 200 ms eye velocity starts to decay, and position error increases (0, E3) – oculomotor system is no longer able to predict occluded target location. As the target is still not visible, oculomotor system executes saccade (0, S2) to the expected target location. After the occlusion, position error (0, E3) is reduced by executing two saccades (0, S3 and S4) to catch-up with the reappeared target.

All ten trials for same subject and same occlusion are plotted in 0. There one can see two different strategies of oculomotor system behavior: gaze is either left in same position until target reappears (0, 1-3), or is shifted to expected target location by executing voluntary saccades (0, 4-10).

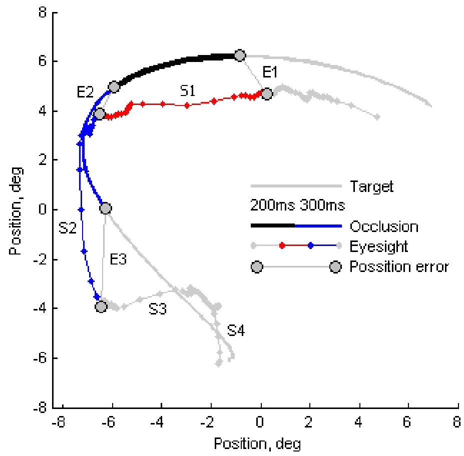

Fig. 3. Trajectories of the target and the eyesight 250 ms before onset and 500 ms after offset of the occlusion. Thick black line (first 200 ms) and thick blue line (last 300 ms) marks occlusion. Corresponding eyesight locations during occlusion is marked by red and blue dash dotted line. Thin grey lines ending with the burbles represent position errors at the onset of the occlusion (E1), *onset + 200 ms* (E2) and at the offset of the occlusion (E3) and connect a corresponding target and eyesight locations.

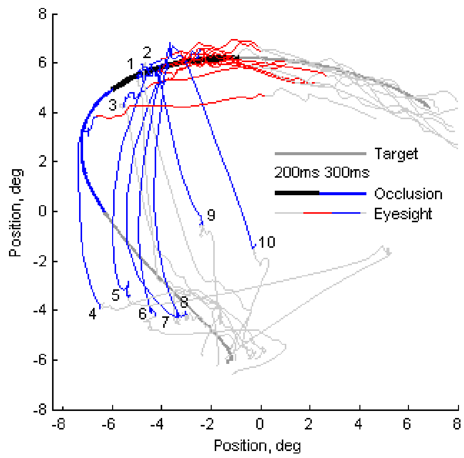

Fig. 4. Trajectories of the target and ten trials of the eyesight 250 ms before onset and 500 ms after offset of the occlusion.

In this research occlusions of 500 ms were used, and this means that subjects had only 300 ms for directing their gaze towards expected target location. Previous results [[4]] show that up to 500 ms after occlusion onset, gaze is not directed to the centre of the screen and position errors calculated between eyesight and target at that point does not differ from those, calculated with the respect of screen centre. Position errors between eyesight and target position at the occlusion offset for different occlusion groups and eyesight distance from the centre of the screen at same time is placed in 0. Comparing data, one can see that position error differ from distance from the centre of the screen. This is due to differences of parameters of the occlusions used in this research.

Velocities of subject SN for one single trial (0, A) all trials (0, B) for the same piece of target trajectory as 0 are plotted. To reduce noise, trials in 0, B are filtered using moving average filter with window size of 50 ms. Movement of the target for selected occlusion is mainly horizontal; therefore velocities represented in 0 are for horizontal channel only.

TABLE I. POSITION ERRORS BETWEEN EYESIGHT AND TARGET POSITION AT THE OCCLUSION OFFSET FOR DIFFERENT OCCLUSION GROUPS AND EYESIGHT DISTANCE FROM THE CENTRE OF THE SCREEN AT SAME TIME. STANDARD DEVIATION AMONG ALL TRIALS IS PLACED IN THE BRACKETS.

	Position error, deg	Distance from the centre, deg
Group A	2,88 (1,58)	5,07 (1,26)
Group B	5,07 (1,4)	4,30 (1,68)
Group C	3,91 (1,28)	6,61 (1,25)

One can see that in all trials subject acts the same: up to 200 ms after occlusion, target is tracked as it was visible. In most of the trials catch-up saccades are executed. These catch-up saccades are planned for execution before occlusion, but because of the motor delays, executed only when occlusion starts. 200 ms after occlusion onset eyesight velocity starts to decay (in most cases eyesight comes complete stop – fixational eye movements appear) and then voluntary saccades are executed to the expected target location. Voluntary saccades appear roughly 350ms after occlusion onset. When target reappears, oculomotor system plans saccades towards new target position, and executes it about 150 ms after occlusion offset. Velocity of slow phase smooth pursuit eye movements starts to increase until matches target velocity – eyesight catches-up with the target. Because of pursuit gain less than 1.0, catch-up saccades (0, S4) are executed to compensate position error.

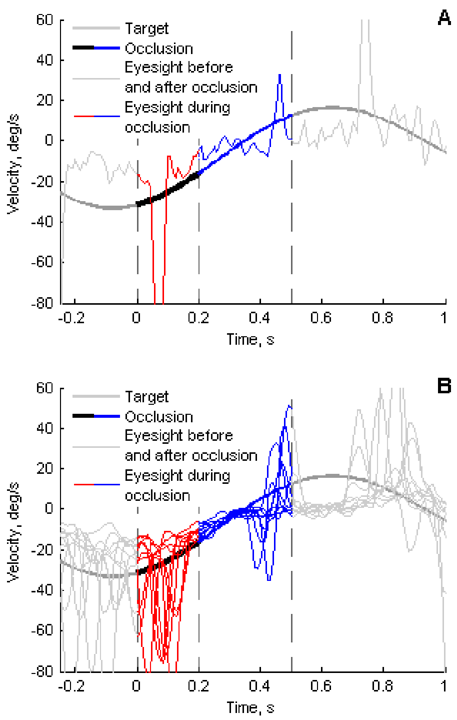

Fig. 5. Velocities of the target (thin grey line) and 10 trials of eyesight 250 ms before onset and 500 ms after offset of the occlusion (thick black – first 200 ms and thick blue line – last 300 ms of the occlusion). Corresponding eyesight velocities during occlusion is marked by red and blue line.

Averaged data shows that position error between target position and eyesight starts to increase only 200 ms after the occlusion onset. Position errors before the occlusion and up to 200 ms after the occlusion onset depend only on target velocity before the occlusion.

Average position errors between target and eyesight trajectories at occlusion *onset - 250 ms* to *offset + 500 ms* (step of 50 ms) for all subjects were calculated (0).

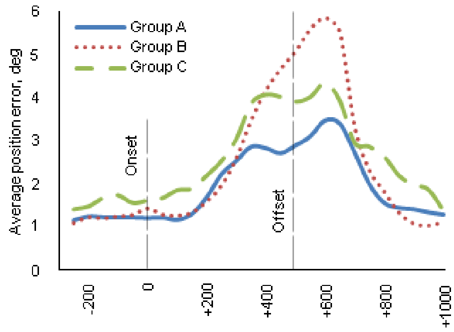

Fig. 6. Average of position errors in the different stages of target occlusion for different groups of occlusions.

Target velocity before group A (18.6 – 25 deg/s) and group B (14.1 – 21 deg/s) occlusions is more or less the same; therefore position error is more or less the same too (1.16 – 1.3 deg for group A and 1.1 - 1.44 deg for group B occlusions). Because of higher target velocity before group C occlusions (27 – 33 deg/s), average position errors from 250 ms before occlusion onset to 200 ms after the occlusion onset are higher (1.42–1.9 deg).

Analyzing eyesight trajectory after prediction period of 200 ms (0, thin blue line), one can notice, that gaze is either left in same position until target reappears or is shifted to expected target location by executing voluntary saccades. Voluntary saccades to expected target location are executed in 73% of the trials. These voluntary saccades are seen in 0 as reduction of position error at time *onset + 350 ms* to *onset + 450 ms*. There is no reduction of position error for group B occlusions. This is because during occlusions in this group target changes its direction to opposite and oculomotor system fails to predict this change.

IV. CONCLUSIONS

To overcome retinal slip and delay in the neural pathways the oculomotor system uses prediction of future target motion to program catch-up saccades to a moving target. This prediction allows tracking occluded target trajectory up to 200 ms. After this period of time, prediction of target position is influenced by the probability of the position of target reappearance accumulated in long-term memory. Depending on occlusion parameters, in most cases oculomotor system is able to reduce position error executing voluntary saccades toward expected target location. Analyzing paths of these gaze shifts, we can see a tendency to shift gaze away from previous target location, similarly, away from the edges of the screen. We suggest that this is due to probability, accumulated in long-term memory, which supports expectation that the target should reappear near the centre of the screen [[4]]. This statement supports basic principles of the Bayesian decision theory. Bayesian statistics defines how new information should be combined with prior beliefs and how information from different modalities should be integrated. Limbs movement control system aims to solve similar problems where the decision is based on notion of ‘cost-to-go” from current state to a target state. The solution changes constantly according to new information coming from the sensory system and minimizes expected value of utility such as muscle energy and movement error.

Determining the appropriate motor command from the CNS could be defined as a decision process. At each point of time, we must select one or few particular commands from the set of possible actions. Decision process is activated by two components: knowledge of the initial position of the limb and knowledge of our objectives. [5].

REFERENCES

[1] J. J. Orban de Xivry, M. Missal, P. Lefevre, “A dynamic representation of target motion drives predictive smooth pursuit during target blanking”, *Journal of Vision*, vol. 8, no. 15, pp. 1–13, 2008. [Online]. Available: http://dx.doi.org/10.1167/8.15.6

[2] J. J. Orban de Xivry, S. Bennet, P. Lefevre, G. R. Barnes, “Evidence for synergy between saccades and pursuit during target disappearance”, *Journal of neurophysiology*, vol. 95, no. 1, pp. 418–27, 2006. [Online]. Available: http://dx.doi.org/10.1152/jn.00596.2005

[3] A. Leigh Mrotek, J. F. Soechting, “Predicting curvilinear target motion through an occlusion”, *Experimental Brain Research*, Springer Berlin / Heidelberg, pp. 99–114, 2007.

[4] R. Zemblys, V. Laurutis, S. Niauronis, „Oculomotor response to occlusions in target trajectory“, in *Proc. of the Biomedical engineering*, p. 238–241, 2011.

[5] K. P. Cording, D. M. Wolpert, „Bayesian decision theory in sensorimotor control“, *Trends in Cognitive Science*, vol. 10, no. 7, pp. 319–326, 2006. [Online]. Available: http://dx.doi.org/10.1016/j.tics.2006.05.003