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Fixational Eye Movements: Influence on the Accuracy in the Target Pointing Tasks

V. Laurutis, R. Zemblys, L. Buivis
Biomedical Engineering Centre, Siauliai University,
Vilniaus str. 141, LT-76353 Šiauliai, Lithuania; phone: +370 41 595837; e-mail: v.laurutis@cr.su.lt

Introduction

Gaze is defined as the absolute position of the eyes in space and depends on both: eye position in the orbit and head position in the space. Thus, the control of gaze requires a coordinated action of eyes, head and, of course, trunk motor systems. In foveate animals, such as we are, changes in eye orientation are required to fixate, i.e., bring an attended detail to the centre of the fovea – the most sensitive place on the retina. Eye movements are required to keep fixated objects relatively stationary when we move and to maintain fixation of moving objects when we sit still.

Fixational movements are controlled by two different neuronal mechanisms. The first allows the person to move his eyes voluntarily and to find the object upon which he wishes to fix his vision. The second is an involuntary mechanism that holds the eyes firmly on the object once it has been found. The involuntary locking type of fixation results from a negative feedback mechanism that prevents the object of attention from leaving fovea. Normally the eyes have three types of continuous but imperceptible movements: a continuous tremor at a rate of 30 to 80 Hz caused by successive contractions of the ocular muscles, a slow drift of the eyeballs in the different directions, and sudden flicking movements (microsaccades) that are controlled by the involuntary fixation mechanism. When the target has become fixed on the foveal region on the retina the drifting movements cause it to drift across the cone cells. However, each time when the target drifts as far as the edge of the fovea, a sudden reflex reaction occurs, producing a flicking movement that moves image of the target away from this edge toward the center. These drifting and flicking motions keep the image from leaving the foveal region [1].

If we compare periodical drifting and flicking processes in the fixational eye movements control system with video scanning mode in all technical video equipment we can find large similarity. Difference is that scanning in video cameras and monitors has strictly determined mode when drifting and flicking fixational eye movements has random directions and durations. Nevertheless, we can claim that video scanning mode in both physiological and technical systems has the same purpose i. e. to get information from the image. This could be proved executing experiment which is called image stabilization on the retina [2]. During this experiment, viewing target moves together with fixational eye movements therefore scanning (drifting and flicking) process is stopped. In this situation target after one - three seconds will become invisible. Lost of vision during image stabilization on the retina explains the purpose of the scanning fixational eye movements.

Aim and tasks of the work

When the gaze of the operator is used for the target pointing tasks or organizing communication possibilities [3] fixational micromovements could be assumed as the noise eliciting uncertainty of the target direction when line of sight is on the target. Using gaze for pointing tasks scanning fixational eye movements reduce an accuracy of the target direction, therefore possibilities of filtering them must be analyzed.

Characteristics of the eye movements during fixation are investigated and well known [4]. Amplitudes of the microsaccades are in the range 0.1 – 0.9 deg (mean 0.3 deg), frequency – in the range 1 – 3 Hz (mean 2.6 Hz), maximum speed – in the range 10 – 100 degsec^{-1} (mean 30 degsec^{-1}), drifting speed is 0.4 degsec^{-1}.

Purpose of this research is to investigate probability distribution of the eye movements during fixation and answer the question: are scanning characteristics of two eyes correlated or not. Second investigation fulfilled to see how fixational eye movements differ from the different visual tasks, direction of the fixation and psychological concentration of the operator.

Method

Experimental data was obtained from five subjects. Eye movements were recorded using LC Technologies, LTD produced eye tracker *EyeGaze System*. Targets were presented on the computer screen. During first experiment

A, subjects were asked to fixate target (white spot) on the screen. In the second experiment B, subjects fixated not existing target in the middle of the two spots situated in the horizontal line. In the third experiment C, subjects voluntarily fixated imagined target in the dark. Influence of the asymmetrical eye globe muscles tension was investigated changing direction of the target and keeping head of the subject in the primary position (experiment D). Duration of all fixational experiments was 10 sec.). Measuring standard deviation of the scatter of the fixational eye movements during experiment, we defined influence of the subject's concentration on the fixation results.

Experimental results

In the Fig. 1, we can see two-dimensional scatter of the fixational eye movement trajectories for the right eye, left eye and for difference between right and left eyes, obtained during experiments A, B and C. Dots in this figure represent recorded and sampled trajectories. Duration of the trajectories is 10 sec and sampling interval - 8 msec. Represented results shows that smallest scatter was obtained in the experiment A, when subject fixated white spot on the screen. First conclusion could be made that scatter in the vertical direction y is 1.5 – 2 times bigger than in the horizontal x. Second, it was defined that scatter in the horizontal direction is smaller than 0.5 degree and scatter in the vertical direction is smaller than one degree. Most significant finding in this research is approval that fixtional eye movements of the right and left eyes are correlated. It means that during fixation of the target both eyes move approximately in the same way and scatter of the difference of these two movements is significantly smaller.

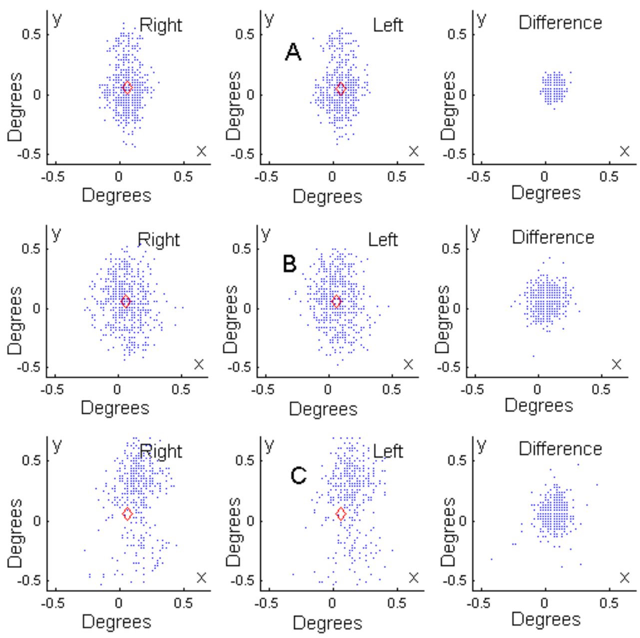

Fig. 1. Two-dimensional scatter of the fixational eye movements obtained: (A) fixating white spot, (B) looking at the not existing target in the middle between two reference dots and (C) fixating imaginary target in the dark. Dots in this figure represent samples of the trajectories obtained every 8 msec which duration is 10 sec

This finding suggests that the target pointing accuracy could be increased using recordings from both eyes and calculating difference between them.

Results of the second experiment B when the subject fixated not existing target in the middle of the two reference spots show that scatter of the recorded data for both eyes are significantly larger. Nevertheless, scanning movements of the right and left eyes in this situation are still highly correlated and scatter of the difference of the movement is small.

In the experiment C, when the subject fixated imaginary dot in the dark scatter of the recorded data is in the same range as in the experiment B. However, correlation of the trajectories of the both eyes is strongly reduced.

Experiments B and C comparing with A defined that scatter of the fixational eye movements when there are no visible target is strongly increased.

Neurophysiology of the fixational eye movements control system explains that fixation of the target in the CNS is controlled by two networks: visual stimulation from the retina and proprioception information from the muscles [5]. When visual stimulation is lost (partly in the experiment B and completely in the experiment C), scatter of the fixational eye movements increases because they are controlled only by information given from the eye globe muscles.

Next experiment was conducted with the purpose to answer the question: how precisely a mean of the two-dimensional probability distribution of the fixational eye movements scatter fits to the target direction. Results of the calculation presented in the Table 1. They show that differences in the horizontal Δx and in the vertical Δy directions are no larger than 10 minutes of arc. Therefore, filtering two-dimensional signal of the fixational eye movements the target pointing accuracy could be increased from 1 degree to 10 min. of arc.

Table 1. Differences between means of the scatter of the fixational eye movements and the target direction (values Δx and Δy)

Subject	Δx, degrees	Δy, degrees
RZ	-0.09	0.15
GD	-0.14	-0.07
NR	-0.03	-0.12
BD	-0.15	0.06
VL	-0.13	0.16

Three pairs of the muscles rotate the eye in the socket [6]. The medial and lateral recti move the visual axis from side to side; the superior and inferior recti move the axis up and down and the superior and inferior oblique roll the eyeball around visual axis. Each pear of muscles act together to move eyeball in such a way as to reduce the displacement from the target to zero. When fixated target is in the centre of the screen push-pull pairs of the eyes muscles have the same values of the innervations' signals obtained from the motoneurons. Because push-pull pairs of the eye globe muscles play important role during fixation we recorded fixational eye movements (experiment D) when fixating spots was presented at the edges of the screen. Obtained results for the two subjects are shown in the Fig. 2. There we can see that standard deviations of the probability distributions changes only 10% when fixation spot is displaced up and down and changes 50% - 100% when spot is displaced to the right and to the left. Higher precision in the horizontal channel could be explained by existing of two eyes situated horizontally and more active vision in this direction (for example reading). Therefore more precise fixational eye movements control system in the horizontal direction could be more quickly affected by the eye globe muscles tension asymmetry.

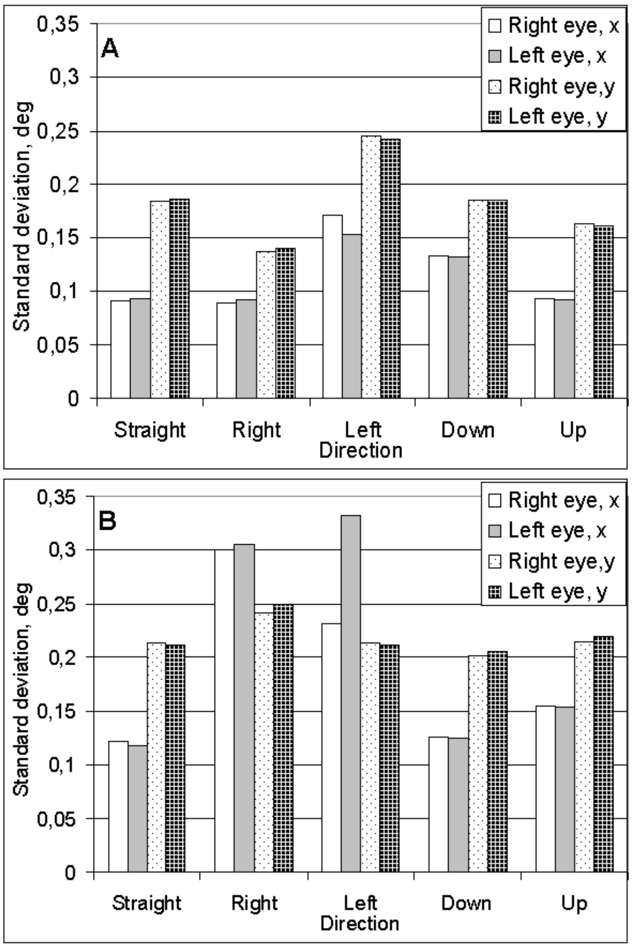

Fig. 2. Comparison of the standard deviations of the scatter of the fixational eye movements when subjects RZ (plot A) and GD (plot B) fixated target presented straight ahead and displaced to the right-left and up-down

Executing experiments, we found that parameters of the fixational eye movements are not stable during one session and do not depend on the concentration of the subject. If means of the two-dimensional scatter of the probability distribution remains approximately constant so standard deviations changes substantially. Fig. 3 shows how standard deviations changes during 10 sec experiment D for subjects RZ (upper plot) and GD (lower plot). In this figure, we can see that for subject RZ standard deviations in the horizontal direction x for both eyes changes only a little. Contrary, in the vertical direction y standard deviation for right eye increases and for left eye decreases 3-4 times. For subject GD during the same experiment three standard deviations increase.

Conclusions

1. Periodical drifting and flicking eye movements during fixation performs scanning of the perceived visual information.

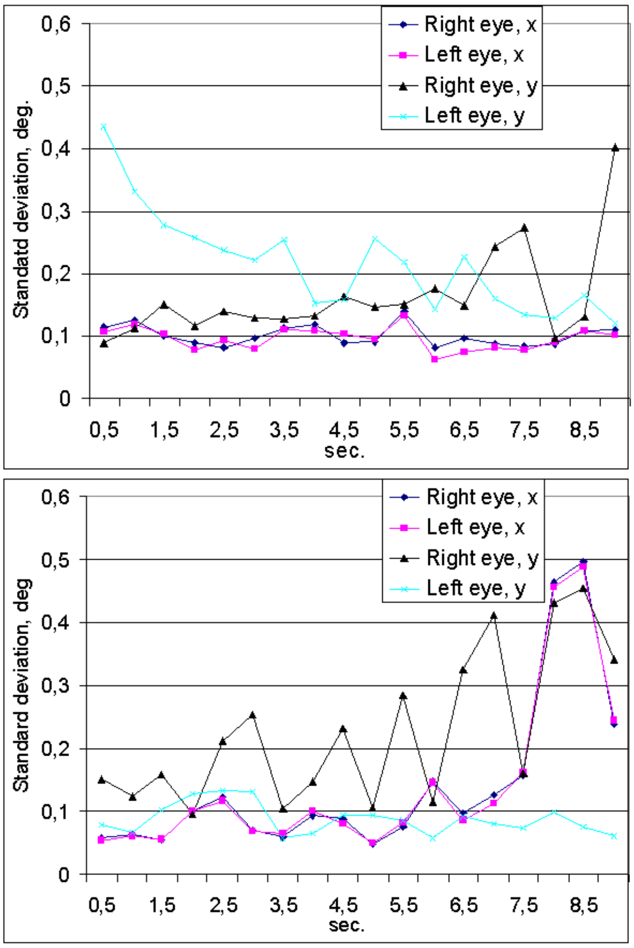

Fig. 3. Changes of the standard deviations during 10 sec target fixating experiment for subjects RZ (upper plot) and GD (lower plot)

2. For both eyes scatter of the fixational eye movements in the horizontal direction is 1.5-2 times smaller than in the vertical direction. It means that precision of the horizontal channel of the fixational eye movements control system is higher than precision of the vertical.
3. Two-dimensional scatter of the differences of the right and left eyes movements are significantly smaller than scatter of the each eye measured separately. Therefore, fixational eye movements of the right and left eyes are correlated. Using this phenomena gaze pointing accuracy could be increased.
4. Scatter of the fixational eye movements is smaller when fixation is elicited to the visible spot in comparison to the imaginary target. Voluntarily fixation without reference target increases two-dimensional scatter of the fixational eye movements.
5. Differences between means of the two-dimensional probability distribution of the fixational eye movements and the target directions stay within 10 min of arc.
6. Standard deviations of the probability distributions changes only 10% when fixation spot is displaced up and

down and changes 100% when it is displaced to the right and to the left.

7. Scatter of the fixational eye movements is not under the influence of the psychological concentration of the operator.

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In this research binocular fixational eye movement were studied. They reduce an accuracy of the defined target direction in the target pointing tasks, therefore possibilities of filtering them was analyzed. It was found that for both eyes two-dimensional scatter of the fixational eye movements in the horizontal direction is 1.5-2 times smaller than in the vertical. Two-dimensional scatter of the differences of the right and left eyes movements are significantly smaller than scatter of the each eye measured separately. Therefore, it was stated that fixational eye movements of the right and left eyes are correlated and using this phenomena gaze pointing accuracy could be increased. Scatter of the fixational eye movements is smaller when fixation is elicited to the visible spot in comparison to the imaginary target. Differences between means of the two-dimensional probability distribution of the fixational eye movements and the target directions stay within 10 min of arc. Standard deviations of the probability distributions changes only 10% when fixation spot is displaced up and down and changes 100% when it is displaced to the right and to the left. Ill. 3, bibl. 5 (in English; summaries in English, Russian and Lithuanian).

В. Лаурутис, Р. Земблис. Л. Буйвис. Фиксационные движения глаз и их влияние на точность определения направления цели, устанавливаемой взглядом // Электроника и электротехника. – Каунас: Технология, 2009. – № 5(93). – С. 91–94.

Исследованы бинокулярные фиксационные движения глаз. Они уменшают точность определенного взглядом направления цели, поэтому необходимо найти способы для их фильтрации. Установлено, что двухмерный разброс фиксационных движений обоих глаз по горизонтальному направлению 1.5-2 раза меньше чем по вертикальному. Двухмерный разброс разницы фиксационных движений правого и левого глаз существенно меньше чем разбросы каждого отдельно взятого глаза. Таким образом установлено, что фиксационные движения правого и левого глаз взаимно коррелированы и поэтому точность определенния взглядом направления цели может быть увеличена. Двухмерный разброс фиксационных движений глаз намного меньше, когда наблюдается реальная цель, по сравнению с тем, когда цель только представленная. Разница между математическим ожиданием двухмерного распределения вероятностей фиксационных движений глаз и реальной целью непревышает 10 угловых минут. Стандартное отклонение математического ожиданиия двухмерного распределения вероятностей фиксационных движений глаз увеличиваеться только на 10% , когда фиксируемая точка перемещается вверх или вниз, и на 100%, когда фиксируемая точка перемещается на право и на лево. Ил. 3, библ. 5 (на английском языке, рефераты на английском, русском и литовском яз.).

V. Laurutis, R. Zemblys. L. Buivis. Fiksaciniai akių judesiai ir jų įtaka taikinio krypties nustatymo žvilgsniu tikslumui // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2009. – Nr. 5(93). – P. 91–94.

Tiriami žmogaus binokuliniai fiksaciniai akių judesiai. Jie sumažina taikinio krypties nustatymo žvilgsniu tikslumą, todėl reikia numatyti būdus, kaip juos būtų galima nufiltruoti. Nustatyta, kad abiejų akių fiksacinių judesių dvimatė sklaida horizontalia kryptimi yra 1,5–2 kartus mažesnė negu vertikalia. Dešinės ir kairės akių fiksacinių judesių skirtumo dvimatė sklaida yra gerokai mažesnė už kiekvienos atskirai paimtos akies dvimatę sklaidą. Taigi nustatyta, kad dešinės ir kairės akių fiksaciniai judesiai yra tarpusavyje koreliuoti ir, panaudojant šią savybę, taikinio nustatymo žvilgsniu tikslumą galima padidinti. Fiksacinių akių judesių sklaida yra kur kas mažesnė, kai yra stebimas realus taikinys, palyginti su tuo, kai žiūrima į įsivaizduojamą taikinį. Skirtumas tarp fiksacinių akių judesių dvimačio tikimybinio skirstinio matematinės vilties ir realios taikinio krypties neviršija 10 kampo minučių. Kai fiksacijos taškas pastumiamas aukštyn ar žemyn, to paties tikimybinio skirstinio standartiniai nuokrypiai padidėja tiktai 10 %, o kai fiksacijos taškas pastumiamas į dešinę ar į kairę, – 100%. Il. 3, bibl. 5 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).