cognitive science in moscow

Top-down and Bottom-up Attention during Oculomotor Task Performance: Effects of Aging

Alexandra S. Litvinova
M.V. Lomonosov Moscow State University, Moscow, Russia

Patricia O. Ratmanova
M.V. Lomonosov Moscow State University, Moscow, Russia

Dmitry A. Napalkov
M.V. Lomonosov Moscow State University, Moscow, Russia

Abstract. The aim of the study was to reveal how aging affects eye movements in visual tasks of varying complexity. Young healthy volunteers (17–30 years) and older healthy volunteers (50–75 years) took part in the study. The volunteers were asked to perform visually-guided and self-paced eye movements. According to our data, aging affects eye movements in simple visual tasks, which mainly involves bottom-up attention. On the contrary, we found no significant difference between the two age groups in more complicated tasks involving predominantly top-down control. We suggest that older individuals engage a more distributed neocortical network during complex tasks to maintain the same level of saccadic performance as in younger persons.

Correspondence: Alexandra S. Litvinova, litvinova@neurobiology.ru, Lomonosov Moscow State University, Department of Biology, Vorob'evy Gory, 1, corp. 12, GSP-1, 119234 Moscow, Russia; Patricia O. Ratmanova, patricia@neurobiology.ru; Dmitry A. Napalkov, napalkov@neurobiology.ru

Keywords: aging, attention, visually-guided saccades, self-paced saccades

Acknowledgments. The authors would like to thank Alexander V. Latanov for the opportunity to use eye-tracking equipment.

Received 10 August 2015, accepted 25 September 2015.

Introduction

Are young and old people equally efficient in oculomotor task performance? This question remains open. The most common age-related changes in eye movement characteristics are the following: an increase in saccadic latencies, velocity alteration, saccadic hypometria, and an increase in the number of errors (Irving, Steinbach, Lillakas, Babu, & Hutchings, 2006; Litvinova et al., 2011). On the other hand, the effects of aging are not so definite in natural scenes eye-tracking (Dowiasch, Marx, Einhäuser, & Bremmer, 2015). The aim of our study was to reveal how aging affects eye movements in visual tasks of varying complexity. We suppose that oculomotor performance in different tasks depends upon the prevailing attention system (bottom-up or top-down). To verify this assumption, we used several tasks with different conditions of visual stimulation and various degrees of movement volition. The most reflexive saccadic eye movements take place in the classic 'Gap' visual stimulation paradigm. 'Overlap' conditions complicate saccadic preparation and execution and actively involve visual attention (Mayfrank, Mobashery, Kimmig,

& Fischer, 1986). Furthermore, we introduced a self-paced saccade task to increase movements' voluntariness (Abel & Douglas, 2007). Eye movement characteristics allow the estimation of various levels and structures of oculomotor system contributions to saccadic performance (Munoz, Broughton, Goldring, & Armstrong, 1998; Litvinova et al., 2011). Moreover, the tasks were supposed to engage bottom-up and/or top-down processes to a different extent.

Method

Participants

Two groups of healthy volunteers took part in the study: a younger group (17 – 30 years, mean age 22 ± 3 (*SD*) years, $n=21$) and an older group (50 – 75 years, mean age 63 ± 6 (*SD*) years, $n=20$). The study conformed to the principles of the Declaration of Helsinki and was approved by the Bioethics Committee of M.V. Lomonosov Moscow State University. Every participant provided written informed consent before taking part in the study.

Procedure

Participants took part in two separate experimental sessions. In the first session, participants performed visually-guided saccades looking at red light-emitting diodes (LEDs). The target lights were located at 6.7° to the right and left, up and down from the central LED (0°). Participants were instructed to fix their gaze on the central LED and to look to an eccentric target as soon as it appeared. Duration of the central LED exposure varied from 700 ms to 1000 ms, while the duration of the eccentric LEDs exposure varied from 1000 ms to 1300 ms. Three visual stimulation paradigms were used (see Fig. 1):

- 'Gap': the eccentric LED appeared 200 ms after the central LED was switched off;

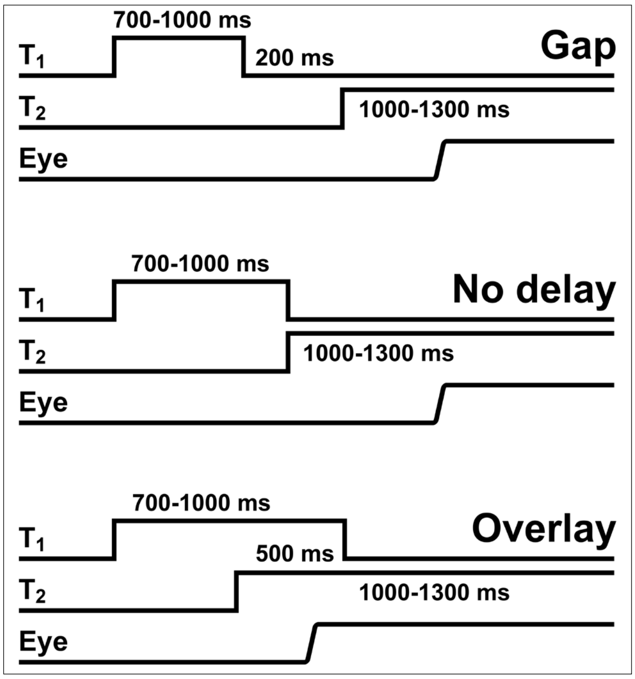

Figure 1. The paradigms used in the visually-guided saccades session. T_1 = central stimulus appearance; T_2 = eccentric target appearance.

- 'No delay': the eccentric LED appeared immediately after the central LED was switched off; and
- 'Overlap': the eccentric LED appeared 500 ms before the central LED was switched off.

There were 180–216 trials of each condition. Target location and stimulation paradigms were pseudorandomly interleaved throughout the session. Visually-guided saccades were recorded by electrooculography. The signal was filtered (0.1–60 Hz) and digitized at a rate of 512 Hz.

In the second session, participants performed self-paced saccades. The following sets of black dots (diameter 0.6°) were presented on the computer screen:

- 3 dots located on the horizontal axis;
- 3 dots located on the vertical axis;
- 3 dots located in the vertices of an imaginary triangle;
- 4 dots located in the vertices of an imaginary square; and
- 6 dots located in the vertices of an imaginary hexagon.

Each set was presented for 20 seconds. The distance between neighbor dots was 6.7°. Participants were instructed to shift their gaze from dot to dot as frequently as possible. The procedure was similar to that used by Litvinova and Bogdanov (in press). Fast digital camera (FastVideo 250V, 'NPO Astek', Russia) was used for eye movement tracking. Eye position was digitized at a rate of 250 Hz. Further details of the equipment can be found in the references (Ermachenko, Ermachenko & Latanov, 2011; Anisimov, Fedorova & Latanov, 2014).

Data analysis. We analyzed the latencies of visually-guided saccades and the number of dots scanned in the self-paced saccade task. Statistical analysis was performed with Statistica 6.0 software. We used a nonparametric Mann–Whitney U–test, ANOVA Kruskal–Wallis analysis and Spearman's rank correlation. The statistical significance threshold was set at $p<.05$. Nonparametric statistics were chosen due to deviations from normal distribution of the visually-guided saccadic latencies and the small sample size in the self-paced saccade task.

Results

The latencies of visually-guided saccades depended on age and the visual stimulation paradigm. Saccadic latencies (see Figure 1 and Table 1) in the 'Gap' and 'No delay' paradigms were longer in the older group in comparison with younger persons ($Z=4.99$, $p<.001$ and $Z=11.94$, $p<.001$ respectively, U–test). Meanwhile, there was no significant difference between the age groups in the more complicated 'Overlap' paradigm ($Z=0.54$, $p=.590$, U–test). Age affected eye movement latencies in 'Gap' ($H(1, N=4494)=25.0$, $p<.001$, ANOVA Kruskal-Wallis; $R=0.074$, $p<.001$, Spearman's rank correlation) and 'No delay' ($H(1, N=4854)=142.5$, $p<.001$, ANOVA Kruskal–Wallis; $R=0.171$, $p<.001$, Spearman's rank correlation) paradigms, but not in the 'Overlap' paradigm ($H(1, N=4356)=0.3$, $p=.590$, ANOVA Kruskal-Wallis; $R=0.008$, $p=.590$, Spearman's rank correlation).

Self-paced saccade performance varied through the images presented (see Figure 2 and Table 2). Older persons scanned fewer dots in the tasks with three dots on the horizontal or vertical axis ($Z=2.30$, $p=.022$, U–test; $R=0.558$, $p=.016$, Spearman's rank correlation and $Z=2.12$, $p=.034$,

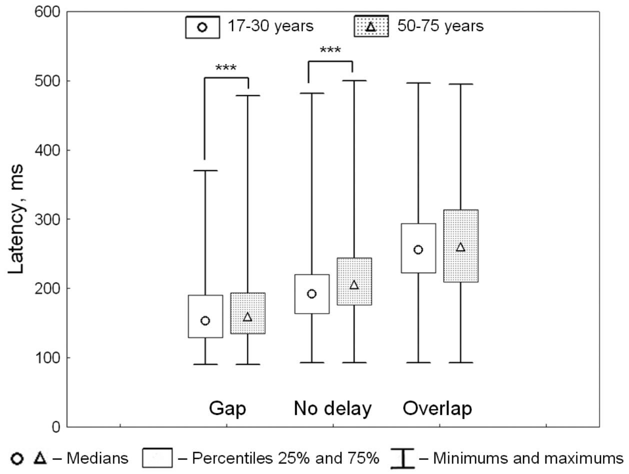

Figure 2. Latencies of visually-guided saccades in 'Gap', 'No delay' and 'Overlap' visual stimulation paradigms in the two age groups. *** – $p < .001$, U–test.

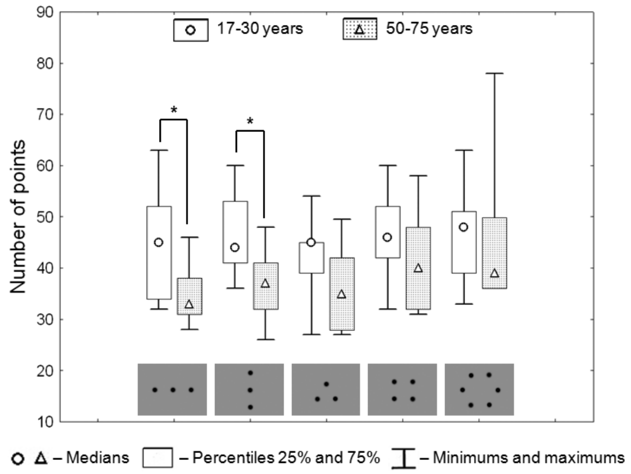

Figure 3. The number of dots scanned by participants within 20 seconds in different conditions of visual stimulation. * – $p < .05$, U–test.

Table 1. Saccadic latencies (ms) in visually-guided saccade task: descriptive statistics

Age group	Paradigm	Median	Minimum	Maximum	Percentile 25%	Percentile 75%
17–30 years	Gap	154	90	370	129	190
	No delay	192	93	482	164	220
	Overlap	256	93	497	223	294
50–75 years	Gap	159	90	478	135	194
	No delay	205	93	500	176	244
	Overlap	260	93	495	209	314

Table 2. The number of dots scanned within 20 seconds in self-paced saccade task: descriptive statistics

Age group	Paradigm	Median	Minimum	Maximum	Percentile 25%	Percentile 75%
17–30 years	1	45	32	63	34	52
	2	44	36	60	41	53
	3	45	27	54	39	45
	4	46	32	60	42	52
	5	48	33	63	39	51
50–75 years	1	33	28	46	31	38
	2	37	26	48	32	41
	3	35	27	50	28	42
	4	40	31	58	32	48
	5	39	36	78	36	50

U–test; $R = 0.516$, $p = .028$, Spearman's rank correlation respectively). There was no significant difference between younger and older participants when they scanned the dots located in the vertices of the imaginary geometric figures.

Discussion

We manipulated the degree of voluntary control of eye movements, varying the number of stimuli and the way of their presentation. We assumed that bottom-up attention was more active in the 'simple' task with less voluntary movements, although we could not absolutely exclude the involvement of top-down processes. According to our data, oculomotor performance decreased in the older group in the simple tasks only. Saccadic latencies increased in the 'Gap' and 'No delay' paradigms, when the participants could see only one stimulus at a time. In this case, saccades were generated reflexively to a target, which appeared suddenly. We suppose that bottom-up attention was engaged to a greater extent in these tasks. We obtained similar results in the self-paced saccades task. Pronounced age-related changes were observed in the tasks with fewer stimuli.

The 'Overlap' paradigm requires activation of selective visual attention and involves the parietal and frontal cortices in saccade preparation (Mayfrank et al., 1986). In the 'Overlap' conditions, there was no difference in saccadic latencies between younger and older persons. Moreover, the older participants were as efficient as younger ones when they scanned more complicated sets of dots perceived as geometric figures. We suppose that the parietal cortex was more involved in this kind of complex task.

Bottom-up and top-down processes depend on age (Açık, Sarwary, Schultze-Kraft, Onat, & König, 2010). Presumably, top-down attention becomes more important with age, while bottom-up attention weakens during the lifespan. Apparently, functional reorganization in brain activity is associated with these changes. Previous fMRI studies of saccadic performance showed that older participants had increased cortical activation in parietal and frontal eye fields compared to younger ones (Nelles, de Greiff, Pscherer, & Esser, 2009). An age-related shift in activity from posterior to frontal brain regions was demonstrated in another study (Raemaekers, Vink, van den Heuvel, Kahn, & Ramsey, 2006). The observed increased activation pattern of older participants suggests a different strategy in advanced age for maintaining the same performance during the saccade task. There may be an additional recruitment within the frontoparietal network to support neuronal processing and maintain task performance despite degeneration of gray and white matter components (Nelles et al., 2009).

Conclusions

Our study showed that the effects of aging on oculomotor performance are revealed in simple visual tasks presumably engaging bottom-up attention. More complicated experimental conditions involve mostly top-down attention which could be accompanied by enhanced activity of the frontal and parietal cortices. We suggest that older individuals engage a more distributed neocortical network during complex tasks to maintain the same level of saccadic performance as in younger persons.

References

Abel, L.A., & Douglas, J. (2007). Effects of age on latency and error generation in internally mediated saccades. *Neurobiology of Aging, 28*(4), 627–637. doi:10.1016/j.neurobiolaging.2006.02.003

Açik, A., Sarwary, A., Schultze-Kraft, R., Onat, S., & König, P. (2010). Developmental changes in natural viewing behavior: bottom-up and top-down differences between children, young adults and older adults. *Frontiers in Psychology, 1*, 207. doi:10.3389/fpsyg.2010.00207

Anisimov, V.A., Fedorova, O.V., & Latanov, A.V. (2014). Eye movement parameters in reading the sentences with syntactic ambiguity in Russian language. *Hunam Physiology, 40*(5), 521–531. doi:10.7868/S013116461404003

Dowiasch, S., Marx, S., Einhäuser, W., & Bremmer, F. (2015). Effects of aging on eye movements in the real world. *Frontiers in Human Neuroscience, 9*, 46. doi:10.3389/fnhum.2015.00046

Ermachenko, N.S., Ermachenko, A.A., & Latanov, A.V. (2011). [Integration of videooculography and encephalography for investigation of visual selective attention in humans]. *Zhurnal Vysshei Nervnoi Deiatelnosti Imeni I. P. Pavlova, 61*(5), 631–640. (In Russian).

Irving, E.L., Steinbach, M.J., Lillakas, L., Babu, R.J., & Hutchings, N. (2006). Horizontal saccade dynamics across the human life span. *Investigative Ophthalmology and Visual Science, 47*(6), 2478–2484. doi:10.1167/iovs.05-1311

Litvinova, A.S., & Bogdanov, R.R. (in press). [Letter cancellation test performance in healthy subjects and patients with Parkinson's disease during aging]. *Psychology. Journal of the Higher School of Economics.* (In Russian).

Litvinova, A.S., Ratmanova, P.O., Evina, E.I., Bogdanov, R.R., Kunitsyna, A.N., & Napalkov, D.A. (2011). Age-related changes in saccadic eye movements in healthy subjects and patients with Parkinson's disease. *Human Physiology, 37*(2), 161–167. doi:10.1134/S0362119711010117

Mayfrank, L., Mobashery, M., Kimmig, H., & Fischer, B. (1986). The role of fixation and visual attention in the occurrence of express saccades in man. *European Archives of Psychiatry and Neurological Sciences, 235*(5), 269–275. doi:10.1007/BF00515913

Munoz, D.P., Broughton, J.R., Goldring, J.E., & Armstrong, I.T. (1998). Age-related performance of human subjects on saccadic eye movement tasks. *Experimental Brain Research, 121*(4), 391–400. doi:10.1007/s002210050473

Nelles, G., de Greiff, A., Pscherer, A., & Esser, J. (2009). Age-related differences of saccade induced cortical activation. *Neuroscience Letters, 458*(1), 15–18. doi:10.1016/j.neulet.2009.04.026

Raemaekers, M., Vink, M., van den Heuvel, M.P., Kahn, R.S., & Ramsey, N.F. (2006). Effects of aging on BOLD fMRI during prosaccades and antisaccades. *Journal of Cognitive Neuroscience, 18*(4), 594–603. doi:10.1162/jocn.2006.18.4.594

спецвыпуск

Произвольное и непроизвольное внимание в глазодвигательных задачах: возрастные аспекты

Александра Сергеевна Литвинова
МГУ имени М.В. Ломоносова, Москва, Россия

Патриция Олеговна Ратманова
МГУ имени М.В. Ломоносова, Москва, Россия

Дмитрий Анатольевич Напалков
МГУ имени М.В. Ломоносова, Москва, Россия

Аннотация. Исследование посвящено возрастным изменениям параметров зрительно-вызванных и произвольных движений глаз в зависимости от сложности зрительной среды. Показано, что возрастные изменения параметров движений глаз в большей степени выражены в более простых условиях зрительной стимуляции, связанных с большим вовлечением процессов непроизвольного внимания. Напротив, с увеличением количества стимулов, одновременно присутствующих в зрительном поле, то есть в ситуации, требующей подключения произвольного внимания, различия в успешности выполнения задания между молодыми добровольцами и участниками старшего возраста нивелировались. Обсуждается активация системы произвольного внимания в старшем возрасте, сопровождающаяся более активным вовлечением корковых глазодвигательных полей в процесс подготовки и выполнения саккад, что, предположительно, позволяет компенсировать негативные возрастные изменения при выполнении сложных глазодвигательных задач.

Контактная информация: Александра Сергеевна Литвинова, litvinova@neurobiology.ru, 119234 Россия, Москва, Ленинские горы 1-12; Патриция Олеговна Ратманова, patricia@neurobiology.ru; Дмитрий Анатольевич Напалков, napalkov@neurobiology.ru

Ключевые слова: внимание, зрительно-вызванные саккады, произвольные саккады, возрастные изменения

Благодарности. Авторы выражают признательность профессору А.В. Латанову за возможность работать с оборудованием для видеорегистрации движений глаз.

Статья поступила в редакцию 10 августа 2015 г. Принята в печать 25 сентября 2015 г.

Литература

Ермаченко Н.С., Ермаченко А.А., Латанов А.В. Интеграция видеоокулографии и электроэнцефалографии для исследования зрительного селективного внимания у человека // Журнал высшей нервной деятельности им. И.П. Павлова. 2011. Т. 61. № 5. С. 631–640.

Литвинова А.С., Богданов Р.Р. Возрастные особенности выполнения теста «Корректурная проба» в норме и при болезни Паркинсона // Психология. Журнал Высшей школы экономики. В печати.

Abel L.A., Douglas J. Effects of age on latency and error generation in internally mediated saccades // Neurobiology of Aging. 2007. Vol. 28. No. 4. P. 627–637. doi:10.1016/j.neurobiolaging.2006.02.003

Açik A., Sarwary A., Schultze-Kraft R., Onat S., König P. Developmental changes in natural viewing behavior: bottom-up and top-down differences between children, young adults and older adults // Frontiers in Psychology. 2010. Vol. 1. P. 207. doi:10.3389/fpsyg.2010.00207

Anisimov V.A., Fedorova O.V., Latanov A.V. Eye movement parameters in reading the sentences with syntactic ambiguity in Russian language // Hunam Physiology. 2014. Vol. 40. No. 5. P. 521–531. doi:10.7868/S013116461404003

Dowiasch S., Marx S., Einhäuser W., Bremmer F. Effects of aging on eye movements in the real world // Frontiers in Human Neuroscience. 2015. Vol. 9. P. 46. doi:10.3389/fnhum.2015.00046

Irving E.L., Steinbach M.J., Lillakas L., Babu R.J., Hutchings N. Horizontal saccade dynamics across the human life span // Investigative Ophthalmology and Visual Science. 2006. Vol. 47. No. 6. P. 2478–2484. doi:10.1167/iovs.05-1311

Litvinova A.S., Ratmanova P.O., Evina E.I., Bogdanov R.R., Kunitsyna A.N., Napalkov D.A. Age-related changes in saccadic eye movements in healthy subjects and patients with Parkinson's disease // Human Physiology. 2011. Vol. 37. No. 2. P. 161–167. doi:10.1134/S0362119711010117

Mayfrank L., Mobashery M., Kimmig H., Fischer B. The role of fixation and visual attention in the occurrence of express saccades in man // European Archives of Psychiatry and Neurological Sciences. 1986. Vol. 235. No. 5. P. 269–275. doi:10.1007/BF00515913

Munoz D.P., Broughton J.R., Goldring J.E., Armstrong I.T. Age-related performance of human subjects on saccadic eye movement tasks // Experimental Brain Research. 1998. Vol. 121. No. 4. P. 391–400. doi:10.1007/s002210050473

Nelles G., de Greiff A., Pscherer A., Esser J. Age-related differences of saccade induced cortical activation // Neuroscience Letters. 2009. Vol. 458. No. 1. P. 15–18. doi:10.1016/j.neulet.2009.04.026

Raemaekers M., Vink M., van den Heuvel M.P., Kahn R.S., Ramsey N.F. Effects of aging on BOLD fMRI during prosaccades and antisaccades // Journal of Cognitive Neuroscience. 2006. Vol. 18. No. 4. P. 594–603. doi:10.1162/jocn.2006.18.4.594