Original Article

Age-related Saccadic Reaction Time Associated with Attention and Working Memory

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ABSTRACT

Objective: This study examined saccadic reaction time (SRT) in visually guided saccades according to age and its relationship with attention and working memory. **Materials and Methods:** The study participants were divided into three groups: young adulthood (18–39 years), middle adulthood (40–59 years old), and older age groups (over 60 years). A total of 85 participants, including 20 young aged, 26 middle aged, and 39 older aged, participated in the study. SRT was recorded using the EyeLink 1000 Plus eye tracker, and 32 trials were conducted. In addition, neuropsychological tests assessing attention and working memory including the Trail Making Test (TM), Digit Span (DS), and Stroop test were applied to the participants. **Results:** SRTs were prolonged in the middle adulthood ($P = 0.026$) and older age group compared with young adulthood ($P = 0.002$). However, SRT did not differ between the middle adulthood and older age groups ($P > 0.05$). In addition, SRT was moderately positively and negatively correlated with TM-A ($r = 0.355$, $P = 0.001$), TM-B ($r = 0.460$, $P < 0.001$), TM-B-A ($r = 0.433$, $P < 0.001$), and DS backward ($r = -0.409$, $P < 0.001$) that is visual attention and working memory. **Conclusion:** SRT may be affected by age. This appears to be part of the visual attention and working memory associated with the saccadic decision-making process.

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INTRODUCTION

The use of eye movement technology has increased in recent years. Eye movement recording is preferred because provides objective, reliable, and rapid access to results.[1] Saccade tasks are the most commonly used method for recording eye movements in the laboratory. Saccades are rapid eye movements in which the eye jumps from one point to another in the visual field.[2] Parameters such as saccadic reaction time (SRT), peak velocity, amplitude, and accuracy of saccades are evaluated. SRT refers to the time between the appearance of a stimulus and the initiation of eye movement in saccade task.[1]

The literature shows that the prosaccade and antisaccade are the most commonly used saccade tasks. The prosaccade involves directing the gaze toward the sudden stimulus.[2] The antisaccade requires looking in the direction opposite to the sudden stimulus.[3] Visually guided saccades or prosaccades are used to demonstrate different cognitive tasks including visual attention and cognitive control processes required to perform simple behavioral tasks.[4] Visually guided prosaccades are based on a simple stimulus-response mapping in which the eye movement is directed rapidly and accurately toward a peripheral stimulus. Decision-making processes slow the SRT of these basic visual motor responses to ensure that an appropriate saccade target is selected.[1] In the prosaccade task, a saccade is initiated approximately 150 ms after the visual stimulus appears and is completed in 50 ms or less, depending on the distance of the peripheral

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stimulus. However, SRTs can vary from trial to trial, depending on interindividual differences and paradigm design.[4]

Some changes occur in the visual system with increasing age. Many studies have investigated altered SRTs associated with various saccade tasks in adults, but relatively few have addressed age-related SRTs.[5-11] According to these studies, there is no consensus regarding the relationship between prosaccade SRT and age. Some studies reported changes in SRT with increasing age. However, others have suggested that SRT does not change with increasing age. The SRT can be influenced by the characteristics of the paradigm, such as the eccentricity of the stimulus, the number of trials, and the characteristics of the participants, such as age group.[1]

Our study aimed to investigate whether prosaccade SRT changes with age. In addition, this study examines the relationship between prosaccade SRT and neuropsychological tests that evaluate attention and working memory. For this purpose, we hypothesized that SRT will become longer with increasing age. Most studies related to SRT and age included young and old groups and overlooked the middle-aged group or included only older individuals and overlooked the young- and middle-aged group.[5,7-11] The study by Munoz *et al.*[6] included individuals aged 5–79 years, forming 11 subgroups. We will address age groups in a continuum. Thus, we included individuals over the age of 18 years and divided the age groups into early adulthood, middle adulthood, and old age.

Materials and Methods

Participants

A total of 85 participants participated in this experimental study. This study was conducted between 2019 and 2023 at Dokuz Eylül University, Institute of Health Sciences, Department of Neurosciences, Balance and Eye Movement Recording Laboratory. Participants were recruited from the clinical settings of the Neurology Outpatient Clinic at Dokuz Eylül University Hospital. Individuals aged over 18 years without any known neurological or psychiatric disorders were included in the study. The Mini-Mental State Examination (MMSE) was administered to eliminate individuals with cognitive difficulties, especially those over 55. The cutoff point of this test for dementia was 23 out of 30, and individuals with a score of 23 and below were excluded from the study.[12,13] The study's participants first underwent a neurological examination by specialized neurologists. Then, specialized neuropsychologists performed neuropsychological tests and eye movement recording procedures.

Participants were divided into three subgroups according to the age classification proposed by Neugarten and Hagestead.[14] Accordingly, the age groups are as follows: young adulthood (20–39 years), middle adulthood (40–59 years), and old age (over 60 years).

The study was conducted in accordance with the principles of the Declaration of Helsinki. This study was approved by the ethics of the Dokuz Eylül University Faculty of Medicine (no.: 2020/04-43). Informed consent was given by the experimenters to all participants.

Neuropsychological tests

Digit Span (DS), Trail Making, and Stroop tests were used to assess attention, working memory, information processing speed, and inhibition skills.

The DS test measures working memory and simple and divided attention and consists of two phases: the DS forward number range and backward.[15] The participant is expected to read the digits of four ranges and then expected to say the same numbers in the same order in the forward DS. Each digit was repeated with two different digit sequences, and the test was terminated at the eight-digit sequence. Participants will read the numbers starting from the three digits and are expected to say the numbers from the end to the beginning in the DS backward. The test ends with a seven-digit number sequence. In both tests, the highest possible range was recorded as the score.

The Trail Making Test evaluates attention, visual scanning, and working memory. It consists of two parts: A and B.[16,17] The Trail Making Test A contains numbers 1–25 scattered. Participants are expected to connect the numbers with a pencil in order without lifting their hands. The time score is calculated during the test. Trail Making Test B includes numbers 1–13 and letters A–K. Participants are asked to connect the numbers from 1 to A and 2 to B with a pencil. The time score is calculated. By subtracting the time of Form A from that of Form B, the B-A time difference score is also calculated. This score was assumed to measure attention, flexibility, and set-shifting skills.

The Stroop test was used to evaluate distractor resistance and inhibition skills.[18,19] The task was to say the color of words with color names. The participant is instructed to perform this task as quickly and accurately as possible. The response time is recorded in seconds.

To assess the depression levels of the participants, the Geriatric Depression Scale was used for individuals over the age of 60 years, and the Beck Depression Inventory was used for individuals under the age of 60 years.[20-23] The anxiety levels of the participants were assessed using the Beck Anxiety Inventory.[24,25]

Saccadic eye movement recordings

Eye movements were recorded using the EyeLink 1000 Plus. The recordings were performed in a dimly lit room. The participant was presented with a white fixation mark (circle) on a black background for 1000 ms, followed by a blank screen for 200 ms (GAP). The participant was then asked to look at a stimulus that suddenly appeared 10^0 to the right or left of the center of the screen for 1000 ms. The direction of the stimulus was presented randomly. The duration between the stimulus onset and the initiation of the correct saccade was determined as the SRT. The SRT was recorded in milliseconds. A total of 32 trials were performed.

Statistical analysis

The Kolmogorov–Smirnov test was used with the Statistical Package for the Social Sciences (SPSS) (SPSS Inc., Chicago, Ill., USA) software to assess the normal distribution of demographic, neuropsychological, and eye movement data. The averages of SRT and neuropsychological test scores in the age groups were evaluated using the Kruskal–Wallis test. The Bonferroni correction was applied in *post hoc* analyses. Spearman's correlation analysis was used to correlate the SRT and cognitive scores.

Table 1: Demographical features of participants

	YA (20–39) (*n*=20)	MA (40–59) (*n*=26)	OA (60+) (*n*=39)
Age	27.9±4.31	51.04±6.47	68.13±6.18
Education	15.75±2.53	12.50±4.51	12.03±2.87
Sex (female/male)	9/11	17/9	26/13
GDS	-	-	6.97±4.78
BDI	8.80±6.10	8.75±6.19	-
BAI	8.60±6.50	6.92±6.98	4.40±4.33
MMSE	29.85±0.36	29.48±0.77	29.20±0.99

The table presents the mean±SDs of age, education, GDS, BDI, BAI, and MMSE. Sex (female/male) is indicated as a frequency. GDS: The Geriatric Depression Scale, BDI: The Beck Depression Inventory, BAI: The Beck Anxiety Inventory, MMSE: The Mini-Mental State Examination, SDs: Standard deviations, YA: Young adulthood, MA: Middle adulthood, OA: Old age

Results

The means and standard deviations of age, education, mood scores, MMSE scores, and sex ratios of all participants are presented in Table 1.

A Kruskal–Wallis *H* test indicated a statistically significant difference in SRTs between age groups (χ^2 (2) = 11.978, P = 0.003). *Post hoc* analyses revealed that the SRTs of the middle adulthood and old age groups were significantly longer than those of the young adulthood. The SRTs of the middle adulthood group were not statistically different from those of the old age group. The mean, standard deviation, minimum, and maximum SRTs in the groups were presented in Table 2.

Significant differences were found between age groups in the DS forward (χ^2 (2) = 11.054, P = 0.004), the DS backward (χ^2 (2) = 15.242, P < 0.001), the Trail Making A (χ^2 (2) =31.843, P < 0.001), the Trail Making B (χ^2 (2) = 18.955, P < 0.001), the Trail Making B-A (χ^2 (2) = 14.067, P = 0.001), and the Stroop test (χ^2 (2) = 29.871, P < 0.001). The Bonferroni-adjusted *post hoc* results for pairwise comparisons between age groups are shown in Table 3.

Statistically positive correlations were found between SRTs and Trail Making A, B, B-A, and age. In addition, statistically significant negative correlations were found between SRT and the MMSE and DS backward. There was no significant relationship between SRT and DS forward and Stroop tests. Correlation coefficients and *P* values are presented in Table 4.

Discussion

In line with our hypothesis, this study revealed that the middle-aged group had longer SRTs than the young-aged group and that the older-aged group had longer SRTs than the young-aged group; however, no difference was found between the older age group and the middle adulthood group in terms of SRTs. The SRT was also found to be associated with age and neuropsychological test results for attention and working memory.

Consistent with our findings, a few studies reported longer SRTs in older individuals than younger individuals.[5,9] The age ranges were approximately 20–

Table 2: Saccadic reaction time

SRT	YA (*n*=20)	MA (*n*=26)	OA (*n*=39)	*P*	Pairwise comparisons (*P*)
Mean±SD	165.05±25.76	197.65±44.11	208.29±50.35	0.003	YA-MA (0.026)
Minimum–maximum	122.36–231.20	116.63–282.95	137.80–338.11		YA-OA (0.002)
					MA-OA (>0.05)

The SRT is presented in milliseconds. YA: Young adulthood, MA: Middle adulthood, OA: Old age, SD: Standard deviation, SRT: Saccadic reaction time

Table 3: Neuropsychological test scores

	YA (*n*=20)	MA (*n*=26)	OA (*n*=39)	*P*	Pairwise comparisons (*P*)
DS forward	6.15±1.30	5.60±1.04	5.03±0.85	0.004	YA-MA (>0.05) YA-OA (0.004) MA-OA (>0.05)
DS backward	5.30±1.34	4.04±0.97	3.89±0.86	<0.001	YA-MA (0.005) YA-OA (0.001) MA-OA (>0.05)
Trail making A	28.35±7.23	37.48±12.78	48.71±12.18	<0.001	YA-MA (0.050) YA-OA (<0.001) MA-OA (0.004)
Trail making B	67.18±23.97	86.78±39.76	129.34±59.85	<0.001	YA-MA (>0.05) YA-OA (<0.001) MA-OA (0.019)
Trail making B-A	38.47±23.62	49.78±38.43	80.34±51.83	0.001	YA-MA (>0.05) YA-OA (0.002) MA-OA (0.018)
Stroop	19.75±5.37	27.56±8.13	32.37±8.04	<0.001	YA-MA (0.005) YA-OA (<0.001) MA-OA (>0.05)

The table presents the means±SDs and *P* values of neuropsychological test scores. SDs: Standard deviations, YA: Young adulthood, MA: Middle adulthood, OA: Old age, DS: Digit Span

Table 4: Correlations between neuropsychological test scores, age, and saccadic reaction time in all participants

SRT	MMSE	DS forward	DS backward	TM A	TM B	TM B-A	Stroop	Age
r	−0.324**	−0.226	−0.409**	0.355*	0.460**	0.433**	0.192	0.433**
P	0.004	0.058	<0.001	0.001	<0.001	<0.001	0.109	<0.001

*Significance at 0.05 level, **Significance at 0.001 level. *r*: Spearman's correlation coefficient and *P*: Significance value. MMSE: The Mini-Mental State Examination, DS: The Digit Span test, TM: The Trail Making Test, SRT: Saccadic reaction time

30 years in the younger group and 60–80 years in the older group. The longer SRTs of the middle age group (age range: 40–59 years) compared with the young adult group (age range: 20–39 years) in our study have not been showed in any other study to our knowledge. Munoz *et al.*[6] divided the participants aged between 5 and 79 years into 11 subage groups. The age ranges are as follows: 5–8, 9–11, 12–14, 15–17, 18–22, 23–29, 30–39, 40–49, 50–59, 60–69, and 70–79 years. They reported that prosaccade SRTs showed a systematic distribution with age. Peltsch *et al.*[11] divided participants aged 60–85 years into five different subage groups. The age group is as follows: 60–64, 65–69, 70–74, 75–79, and 80–85 years. They showed that participants aged 80–85 years had longer SRTs than those aged 60–64 and 65–69 years. Other studies that examined the relationship between SRT and age reported no change in SRTs with age.[7,8,10] The SRT can be influenced by many factors, such as the characteristics of the paradigm, stimulus characteristics, intrapersonal factors, number of participants, and age distribution.[6] The strength of our study is that the middle adulthood group was included in addition to the young and old groups.

Eye movements have been used to gain insight into conditions ranging from psychiatric disorders, such as schizophrenia, to neurological diseases, such as Alzheimer's disease.[1] Similarly, eye movement technology can provide an excellent tool for studying changes in cognitive status and eye movement with increasing age.[4] In the real world, multiple competing stimuli crowd out attention and prevent attention from being directed to each stimulus, thus preventing reflex-like responses.[26] Therefore, selection must be made to determine which stimuli are worthy of attention among other potential stimuli. This selection process is inherently time-consuming and contributes to SRTs.[4] Prosaccade parameters such as SRTs are associated with visual attention and working memory.[10,26] Similar to the relationship between latency and attention, our study revealed that neuropsychological tests assessing visual attention and working memory were related to saccade latency.

Working memory is the process of temporarily storing and processing information.[27] The prefrontal cortex (PFC) exerts top–down control over working memory, which has a very limited capacity.[26] Age-related declines in working memory, selective attention, sustained attention, inhibitory control, working memory, and multitasking skills are observed, and these are attributed to changes in the PFC.[28] It is stated that age-related working memory deficits generally occur from middle age onward.[29,30] In our study, although there was a difference between the young- and middle-aged groups, there was no difference between the middle-aged and older groups in terms of SRTs, which we think measure working memory. Considering the literature mentioned above and our findings, working memory decline begins in middle age. However, SRTs could not distinguish middle-aged and older adults. This finding may be due to the heterogeneous working memory performance of older adults. Additional PFC and parietal regions may be activated as compensatory mechanisms during heterogeneous working memory performance.[31,32]

The limitation of our study is that the age groups were divided into three subsections. More subage groups can be formed with more participants in future studies. The strength of our study is that it treats age as a continuum, including the middle age group, rather than including young and old groups as in the literature.

Conclusion

The SRT may be affected by increasing age. This is related to visual attention and working memory. This seems connected to the visual attention and working memory involved in making saccadic decisions.

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Conflicts of interest

There are no conflicts of interest.

Contribution details

All authors contributed to the study's design, data collection, analysis, interpretation of data, manuscript preparation, and manuscript editing.

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