

# Effects of Refractive Errors and Age on Binocular Function in Normal Adult Population

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## Research article

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# Abstract

**Purpose:** To investigate the relationship between binocular function with gender, ages, and spherical equivalent (SE) .

**Methods:** This observational study enrolled 243 healthy, non-strabismic adults, including 94 men and 149 women aged from 20 to 59 years. The subjects were divided into three groups according to SE: myopic group, emmetropic group and hyperopic group. The subjects were also divided into four groups according to age: 20-29 years group, 30-39 years group, 40-49 years group, and 50-59 years group. The binocular vision function was measured with a synoptophore, including subjective angle (SA), divergence, convergence and fusional vergence range (FVR).

**Results:** The mean values of SA, divergence, convergence and range of fusion for the whole sample group were  $3.33\pm 0.16^\circ$ ,  $9.72\pm 0.26^\circ$ ,  $19.34\pm 0.54^\circ$ , and  $29.06\pm 0.62^\circ$ , respectively. The mean values of SA and divergence in myopic group were significantly larger than the emmetropic group (both  $p < 0.05$ ). SE, SA, divergence and FVR were significantly different among age groups (all  $p < 0.05$ ). Besides, linear regression analysis showed SE was correlated with SA and divergence ( $p = 0.007$ ,  $p = 0.003$ ). Age was correlated with SE, SA, divergence and FVR ( $p < 0.001$ ,  $p < 0.001$ ,  $p = 0.005$ ,  $p = 0.002$ , respectively). In addition, the proportion of SA being in comfort zone (defined as the value of SA located in the middle 1/3 area of FVR) in age groups were statistically different. ( $\chi^2 = 8.283$ ,  $p = 0.041$ )

**Conclusion:** Both SA and motor fusion are associated with age and SE in normal adult population.

## Introduction

Binocular vision is one of the most important factors that affect the visual quality and the ability of precise information perception. It is crucial for one's perception in both static and dynamic situations using binocular single vision[1]. Besides, abnormal binocular vision functions such as convergence insufficiency and divergence insufficiency could lead to asthenopia and visual discomfort. Nowadays, with the increasing use of digital media, demands on the binocular visual system are certainly increasing[2]. It was reported that sixty-three percent of the adults and eighteen percent of adolescents who spend long hours on digital devices had symptoms of asthenopia[2, 3]. Asthenopic symptoms, including burning, irritated, dry and tired eyes, blurred vision, eye fatigue and headache, are becoming increasing complaints of the patients in clinical practice.

Normal binocular vision requires accurate eye alignments and binocular mechanisms for sensory fusion, vergence function and stereopsis[4]. Motor fusional vergence, including convergence and divergence, is the ability to maintain binocular vision through a range of induced vergences until the binocular vision is interrupted and the patient experiences diplopia[5]. Previous researches had found that binocular vision function may be associated with refractive characteristics and different ages. In 1995, Dwyer[6] found that a higher proportion in accommodative or binocular abnormality was associated with some form of refractive errors. It was reported that convergence insufficiency and divergence insufficiency were

associated with refractive error groupings. Convergence insufficiency was more likely to occur in patients with a lower degree of myopia, while divergence insufficiency was more likely to occur in patients with a higher degree of myopia[7]. Another clinical study revealed that high school children (aged between 13 and 18 years) with refractive errors, accommodative or vergence anomalies were more likely to have reduced mean stereoacuity than cases without such anomalies[8]. Kirwan and O'keefe[9] believed that stereopsis was related to anisometropia and that every 0.25 D difference of binocular refraction can cause a 0.5% difference in the retinal image. Fu et al[10] found that for both near and distance, younger children had larger esotropia angles than older children and adults in an acute acquired comitant esotropia population. Additionally, in the patients with intermittent exotropia, the damage of near stereopsis function was significantly different between emmetropia group and anisometropia group[11]. Nevertheless, most of the researches on the binocular vision focused on patients with heterophoria, amblyopia or strabismus, but not normal vision population. Therefore, the relationship of binocular vision function with refractive errors as well as demographic variables (gender, age and so on) in normal population still needs more understanding. Such information will help to understand the features of binocular functions in normal adults of different ages and refractive status.

The purpose of this study was to investigate the features of binocular vision function in a healthy adult population and to evaluate the relationship between binocular parameters with ages, gender and refractive status.

## **Materials And Methods**

### **Subjects**

This is a single-center, cross-sectional study from Sep. 1, 2018 to Nov. 30, 2019 in Jinshan Hospital of Fudan University. A total of 243 subjects were enrolled in this study, including 94 male and 149 female subjects, aged 20 to 59 years. All the subjects were divided into 4 groups according to their ages (20–29 years group; 30–39 years group; 40–49 years group; 50–59 years group). The inclusion criteria were normal health and vision; the best corrected visual acuity (BCVA) for each eye was 1.0; got right position of eyes and normal eye movements. The exclusion criteria were not having stereoscopic vision, having strabismus or strabismic surgery, having microtropia or intermittent decompensated heterophorias, diplopia, having medication with ocular side effects, or neurological and circulatory illness.

The study was approved by the Ethical Committee of Jinshan Hospital of Fudan University. This study complies with The Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans and Uniform Requirements for manuscripts submitted to Biomedical journals. Written informed consent was obtained from all the subjects.

### **Examination**

All participants underwent the eyesubject examinations. This included uncorrected distant visual acuity (VA), manifest refraction, cover test, anterior segment and fundus of the eye examination, the study of the

eye motility into each of the six cardinal positions of gaze, and synoptophore tests. Subjective refraction was measured after an auto-refractor (RK-F1; Canon Corporation, Tokyo, Japan) under non-cycloplegic condition. The tests were performed by an experienced optometrist. Spherical equivalent (SE) was calculated as sphere plus half of negative cylinder. Participants were then grouped into three refractive error categories based on SE according to the following criteria: (1) emmetropia, both eyes were between + 0.50 D and - 0.50 D ( $> -0.50$  D,  $< +0.50$  D); (2) hyperopia, either both eyes were  $\geq +0.50$  D or only one eye was  $\geq +0.50$  D and the fellow eye was emmetropic; (3) myopia, either both eyes were  $\leq -0.50$  D or only one eye was  $\leq -0.50$  D and the fellow eye was emmetropic[12]. As in the condition that one eye was myopic and the fellow eye was hyperopic, they were not included in the analysis[13].

The binocular vision functions including subjective angle (SA), divergence, convergence and fusional vergence range (FVR) were measured with the synoptophore (TSJ-Ⅱ, type A, Changchun Photoelectric Instrument Co., Ltd. China). All patients with refractive errors were told to wear the glasses that provide BCVA for 1–2 week before attending the synoptophore exam. Synoptophore tests were performed according to Ohyagi's study[14]. The value of SA was obtained when the targets were fused by the normal vergence function as a car was seen in the middle of the door. Then, the divergence and convergence were measured when the subjects made a sign when a disruption of fusion appeared, with the synoptophore tubes being slowly abducted or adducted. The FVR was calculated as the value of convergence plus the value of divergence. SA in normal range was defined as the value of SA being in the middle 1/3 area of the FVR, which was considered as the comfort zone when viewing with near work[15].

## Statistical analysis

Both eyes of each subject were examined, and the right eyes was used for analysis. IBM SPSS V.22.0 software was used for data analysis. Considering the data did not fully comply with a normal distribution, Mann-Whitney test was used to detect differences between genders, while one-way ANOVA with Kruskal-Wallis post-hoc test was used to detect differences among different age groups and refractive groups. Linear regression analysis was performed to assess the relationship among ages, SE and other factors. Proportions of normal SA were compared using the Chi-square test. All p values were two-sided and considered statistically significant when  $p < 0.05$ .

## Results

The demographic characteristics of all subjects ( $n = 243$ ), male ( $n = 94$ ) and female ( $n = 149$ ) were shown in Table 1. The mean ages of both groups were  $40.8 \pm 1.02$  years and  $42.8 \pm 0.76$  years, respectively. The mean values of SE, SA, divergence, convergence and FVR were shown in Table 1. No significant differences in the mean values were observed between genders (all  $p > 0.05$ ).

As shown in Table 2, there were significant differences of the mean ages and SE among the three groups ranked as hyperopia group  $>$  emmetropia group  $>$  myopia group, and significant differences were observed in pairwise comparison (all  $p < 0.001$ ). The mean values of SA and divergence in myopic group were significantly higher than emmetropic group ( $p = 0.014$  and  $p = 0.001$ , respectively), but no significant

differences were found between myopic group and hyperopic group (both  $p > 0.05$ ), or hyperopic and emmetropic group (both  $p > 0.05$ ). No significant differences were found among the three groups in the mean values of convergence and FVR ( $p = 0.633$  and  $p = 0.177$ , respectively). Linear regression analysis showed negative correlations between SE with SA ( $r^2 = 0.30$ ,  $p = 0.007$ ) and divergence ( $r^2 = 0.037$ ,  $p = 0.003$ ) (Fig. 1)

SE and binocular vision function in different age groups were shown in Table 3. The mean value of SE in the four age groups were  $-2.07 \pm 0.34$  D,  $-1.54 \pm 0.20$  D,  $-0.70 \pm 0.13$  D and  $-0.36 \pm 0.15$  D, respectively. The mean values of SE, SA, divergence and FVR were significant different among age groups ( $p < 0.001$ ,  $p = 0.010$ ,  $p < 0.001$ , and  $p = 0.008$ , respectively). Post-hoc test showed statistically differences in SE, divergence and range of fusion in groups of 20–29 years and 30–39 years when compared to 40–49 years and 50–59 years (all  $p < 0.05$ ) (Fig. 2). Besides, the mean value of SA in 30–39 years group was significantly larger than 40–49 years group ( $p = 0.011$ ) and 50–59 years group ( $p = 0.004$ ). Linear regression analysis revealed that age was associated with SE, SA, divergence and FVR. With the increases of ages, an increasing tendency was observed in SE ( $r^2 = 0.186$ ,  $p < 0.001$ ; Fig. 3A), while decreasing tendencies in SA ( $r^2 = 0.043$ ,  $p = 0.001$ ; Fig. 3B), divergence ( $r^2 = 0.081$ ,  $p < 0.001$ ; Fig. 3C) and FVR ( $r^2 = 0.044$ ,  $p = 0.001$ ; Fig. 3D) were observed.

The proportion of normal SA was 25.9% in hyperopic group, 47.3% in emmetropic group, and 50.4% in myopic group, respectively. The proportion of abnormal SA was 74.1% in hyperopic group, 52.7% in emmetropic group, and 49.6% in myopic group, respectively. There were no significant differences of the proportion of normal SA among refractive groups ( $\chi^2 = 5.373$ ,  $p = 0.068$ ). As shown in Table 4, the proportions of normal SA in the four age groups were 63.0%, 52.9%, 31.3%, 34.3%, respectively. The proportions of abnormal SA in the four age groups were 37.0%, 47.1%, 53.9%, 65.7%, respectively. There were significant differences of the proportions of normal SA among age groups ( $\chi^2 = 8.283$ ,  $p = 0.041$ ).

## Discussion

In the present study, the values of SA, divergence, convergence and FVR in a normal adult population with different ages and refractive status were reported. For the whole sample group, the average value of divergence amplitude was  $9.72 \pm 0.26^\circ$  and the mean convergence amplitude was  $19.34 \pm 0.54^\circ$ , which was agreement with the previous study. Ohyagi et al[14] reported the normal divergence was  $6^\circ$  to  $10^\circ$  and the normal convergence was  $15^\circ$  to  $20^\circ$ . However, in a population of young female athletes (average aged  $21.55 \pm 0.67$  years), the mean values of divergence and convergence were  $4.74 \pm 1.93^\circ$  and  $12.38 \pm 8.20^\circ$ , which was approximately half of the values in this study[4]. This may be due to different instruments and gradations since that the normal amplitudes of convergence and divergence were described as approximately 25 PD and 10 PD[16], and that 1 degree of arc was approximately equal to 2 PD[4]. Besides, different demographic characteristics of the subjects (ages, refractive status) may also account for these discrepancies.

In this study, myopic subjects had larger SA and divergence than the emmetropic subjects. Besides, both of the values of SA and divergence were correlated with SE values. Although the exact mechanism is not certain, we postulated that for near vision, less accommodative effort is required for clear image in myopic status because of a larger accommodation lag[17]. And for distant vision, the fusional control is weakened due to the blurred image. Therefore, this prolonged suboptimal convergence may lead to a larger divergence amplitude and SA, even leading to break down of the fusional control and may predispose to exotropia. In a systematic review on 7 large-scale population, it was reported that myopia was a risk factor for exotropia[18]. Hashemi et al[19] reported the prevalence of exotropia was significantly higher in myopic individuals, which also supports this postulation. The phenomena in this study may be due to the different accommodative convergence to accommodation ration (AC/A) between myopes and emmetropes[20, 21], though the accommodation amplitude has not been tested in the set of this study. Therefore, further prospective studies were needed to confirm the postulation. In a population of university students, no significant difference was found in fusion amplitude in myopes compared to hyperopes[22]. In agreement with that, no significant difference in the convergence amplitude and FVR was observed among different refractive groups in this study.

Linear regression analysis showed that SA, divergence amplitude and FVR decreased with age. Comparisons of SA, divergence and FVR among different age group showed statistically differences in groups of 20–29 years and 30–39 years when compared to 40–49 years and 50–59 years, suggesting that divergence and FVR had age-related differences (such as, under 40 years and over 40 years). It was well-known that the accommodative system declines with age since one century ago and the heterophoria and fixation disparity increases with age [23.24]. From as early as childhood, the subjective amplitude of accommodation declines with age in response to ciliary muscle contraction, increased lens thickness, decreased lens diameter and increased curvature of the lens[25]. These may account for the decreases of divergence and ranges of fusion. Besides, a decreasing tendency of SA associated to age was observed in this study, showing an esotropic tendency at primary eye position with increasing ages. Similar to the results, it was reported that the prevalence of esophoria was significantly higher in older age groups[19]. However, no correlation was shown between age and convergence in this study, which was consistent with the work of Jiang et al[26].

With increased age, the interval between 35 years and 44 years has been described as the early phase of presbyopia[27]. Patients in this stage were more likely to complain about eyestrain or asthenopia among those with longer durations of near work. In this study, the middle 1/3 area of FVR had age-related differences (such as, under 40 years and FVR was defined as comfort zone and that SA located in the comfort zone was normal. The results showed that the proportion of patient with uncomfortable zone is ranked as 50–59 years > 40–49 years > 30–39 years > 20–29 years. It indicated that the symptoms of presbyopia after long durations of near work and digital usages may correlate with abnormal associations between SA and FVR. Therefore, it is useful to evaluate the binocular function by the synoptophore to predict asthenopia for eyestrain patients. However, though a highest proportion of abnormal SA was observed in hyperopic group, the difference was not statistically significant. In a population of university students with mean age of  $22.8 \pm 3.1$  years, the prevalence of asthenopia was

higher in hyperopic students and astigmatic participants based on cycloplegic refraction[28]. However, in a population of video display operators with mean age of  $46.5 \pm 9.3$  years, no significant association was found between visual fatigue and refractory disorders with the classification based on lenses in use using a lensmeter[29]. Therefore, this discrepancy may due to different ages, classifications of refractive status, and different criteria of asthenopia. Further studies are warranted to confirm the association of normal SA in comfort zone and the occurrences of asthenopia.

There may be several limitations in this study. First, this study had a small sample size and the ages ranged from 20 years to 59 years, thus further studies with larger sample and subjects including juveniles under 20 years and elder person over 60 years are warranted. Moreover, we did not evaluate the asthenopia symptoms of the subjects, which we plan to consider in future studies to investigate the relationship between asthenopia and normal SA.

## Conclusions

In conclusion, the SA and divergence amplitude were associated with SE in normal adults. SE, SA, divergence amplitude and FVR were associated with age. The abnormal relationship between SA and FVR may be associated with ages. As near work demands of digital products increase, the importance of comprehensive binocular vision assessment also increases.

## Abbreviations

SE: Spherical equivalent; SA: subjective angle; FVR: fusional vergence range; BCVA: best corrected visual acuity

## Declarations

### Data Availability

All data in this article are available on request by contacting the corresponding author at the e-mail address: [xdzhou2013@126.com](mailto:xdzhou2013@126.com).

### Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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### **Authors' contributions**

MS, TL and XDZ were responsible for the conception and design of this article. JZ and MS acquired the data. MS, QQH and TL analyzed and interpreted the data. MS wrote the draft. TL and XDZ revised the manuscript critically. All authors have read and approved the final manuscript.

### **Ethics approval and consent to participate**

Not available.

### **Consent for publication**

Not available.

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## Tables

Table 1

Demographic characteristics in group by gender

	Male (n=94)	Female (n=149)	P value
Age (years)	40.8±1.02	42.8±0.76	0.13
SE (D)	-1.16±0.17	-0.89±0.11	0.21
SA (°)	3.14±0.26	3.46±0.20	0.77
Divergence (°)	9.41±0.37	9.91±0.35	0.63
Convergence (°)	20.40±0.94	18.68±0.65	0.19
Range of fusion (°)	29.82±1.08	28.58±0.76	0.51

Table 2

Binocular visual function among different refractive groups

	Hyperopia (n=27)	Emmetropia (n=93)	Myopia (n=123)	P value
Age (years)	51.5±1.05	44.8±0.84	37.9±0.81	< 0.001
SE (D)	0.12±0.33	-0.10±0.02	-1.91±0.13	< 0.001
SA (°)	2.74±0.23	3.09±0.19	3.65±0.27	0.023
Divergence (°)	9.56±0.82	8.63±0.31	10.57±0.41	0.003
Convergence (°)	19.11±1.58	18.95±0.92	19.70±0.74	0.633
Range of fusion (°)	28.67±1.87	27.58±1.03	30.27±0.85	0.117

Table 3

Binocular visual function among different age groups

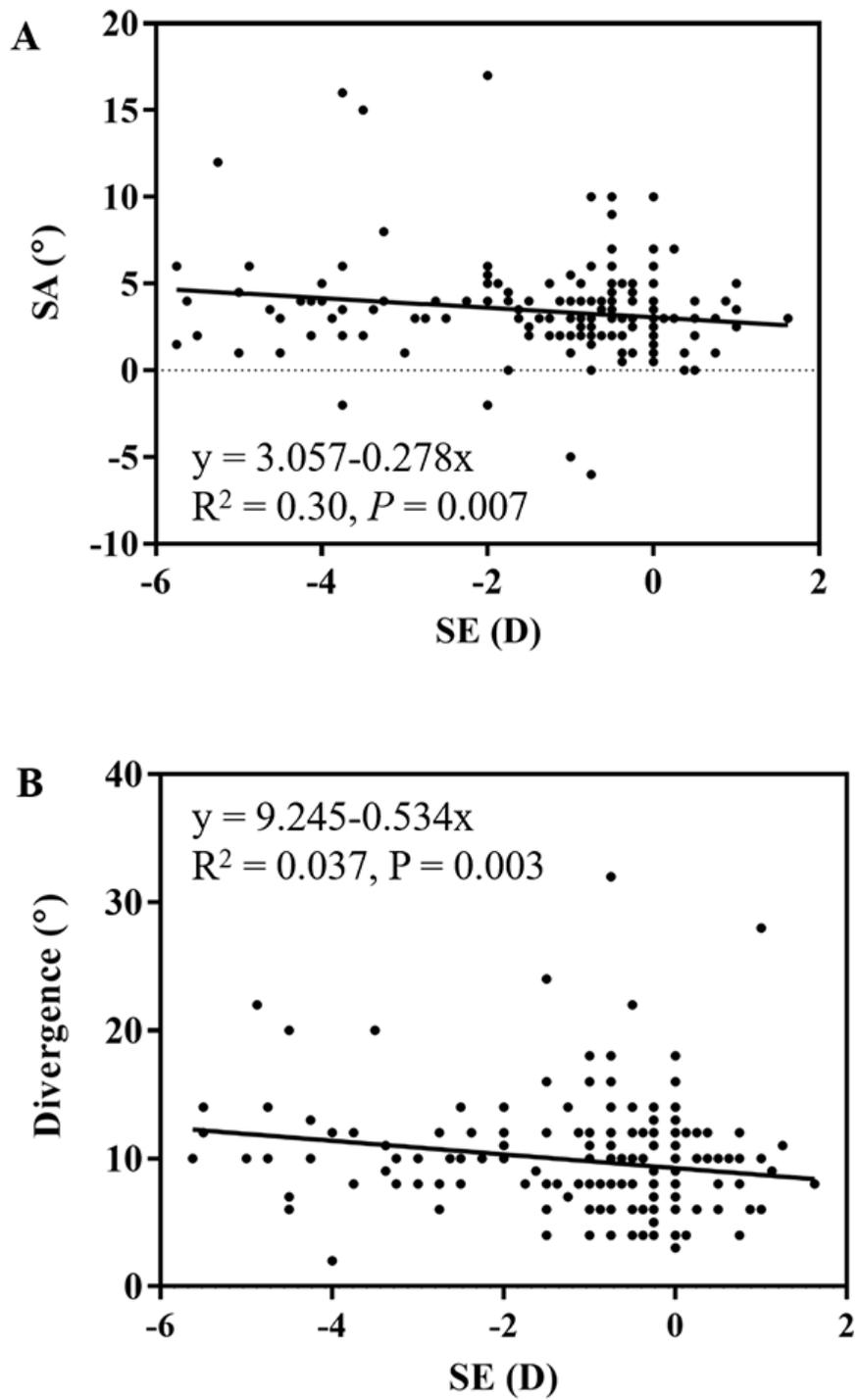
	20-29 years (n=27)	30-39 years (n=70)	40-49 years (n=76)	50-59 years (n=70)	P value
SE (D)	-2.07±0.34	-1.54±0.20	-0.70±0.13	-0.36±0.15	□ 0.001*
SA (°)	4.06±0.92	3.91±0.30	2.90±0.16	2.95±0.20	0.010*
Divergence (°)	12.48±1.18	-10.7±0.47	9.01±0.44	8.41±0.30	□ 0.001*
Convergence (°)	19.52±1.55	20.44±0.97	19.32±0.98	18.21±1.05	0.556
Range of fusion (°)	32.00±1.90	31.16±1.14	28.33±1.12	26.63±1.12	0.008*

Table 4

The proportion of SSA being in comfort zone in different age groups (SSA located in the middle 1/3 area of ranges of fusion serve as normal)

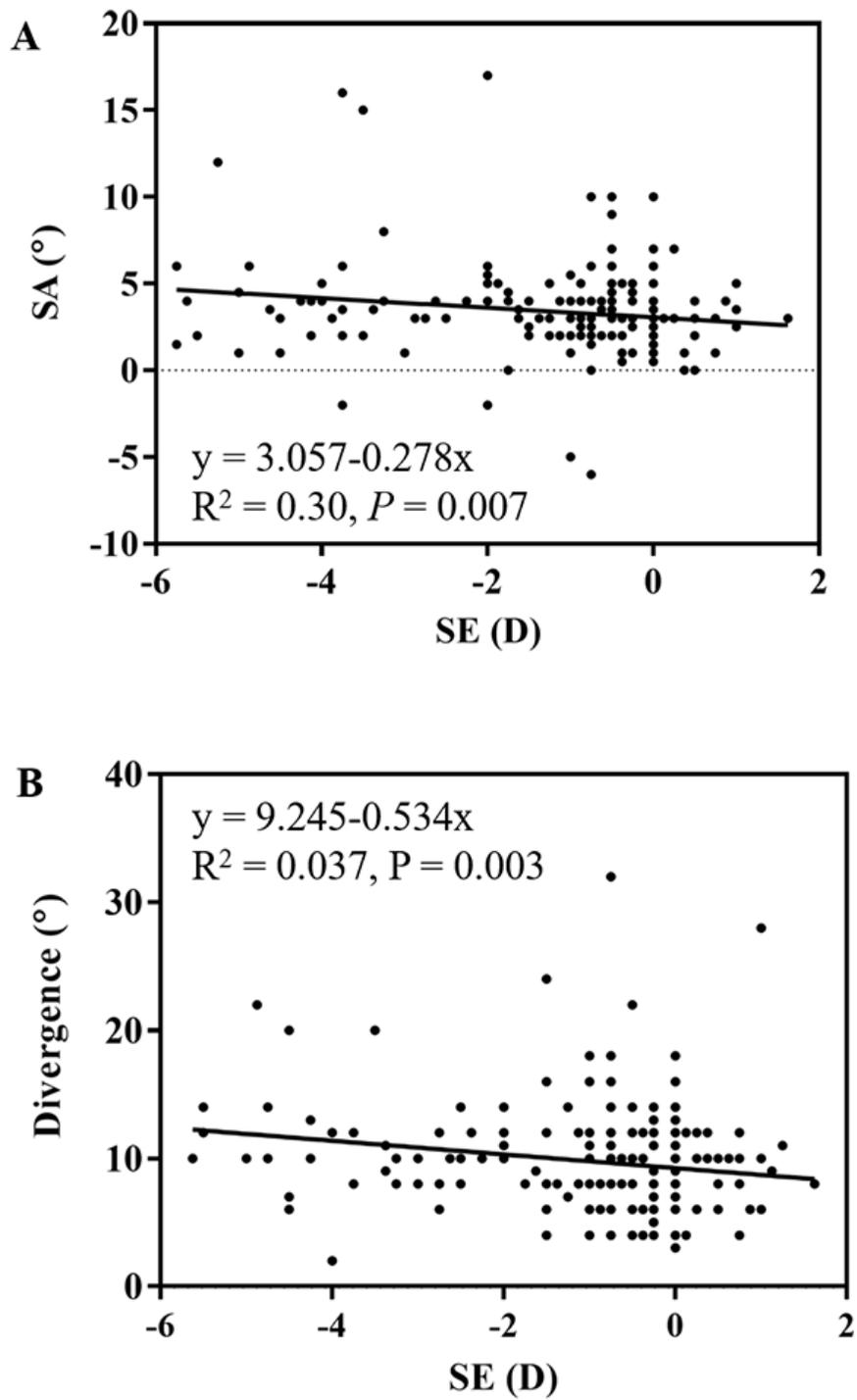
	20-29 years	30-39 years	40-49 years	50-59 years	Total
Normal	17 (63.0%)	37 (52.9%)	35 (31.3%)	24 (34.3%)	111
Abnormal	10 (37.0%)	33 (47.1%)	41 (53.9%)	46 (65.7%)	132
Total	27	70	76	70	243

## Figures



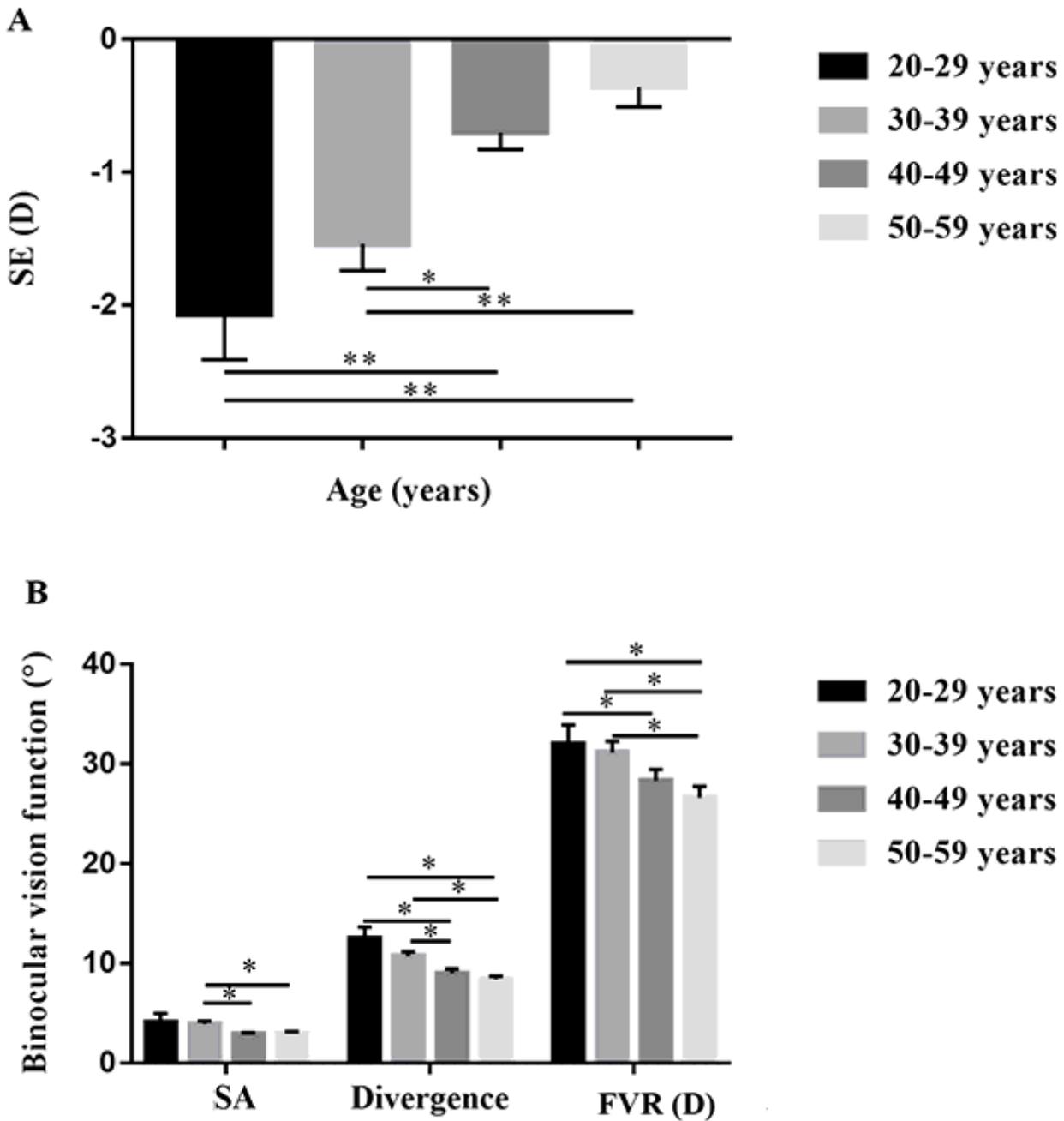
**Figure 1**

The relationship between SE with subjective squint angle and divergence, (A) SSA and SE, (B) divergence and SE. The mean age was  $42.1 \pm 0.61$  years, ranging from 20-59 years. SA, subjective squint angle, SE, spherical equivalent.



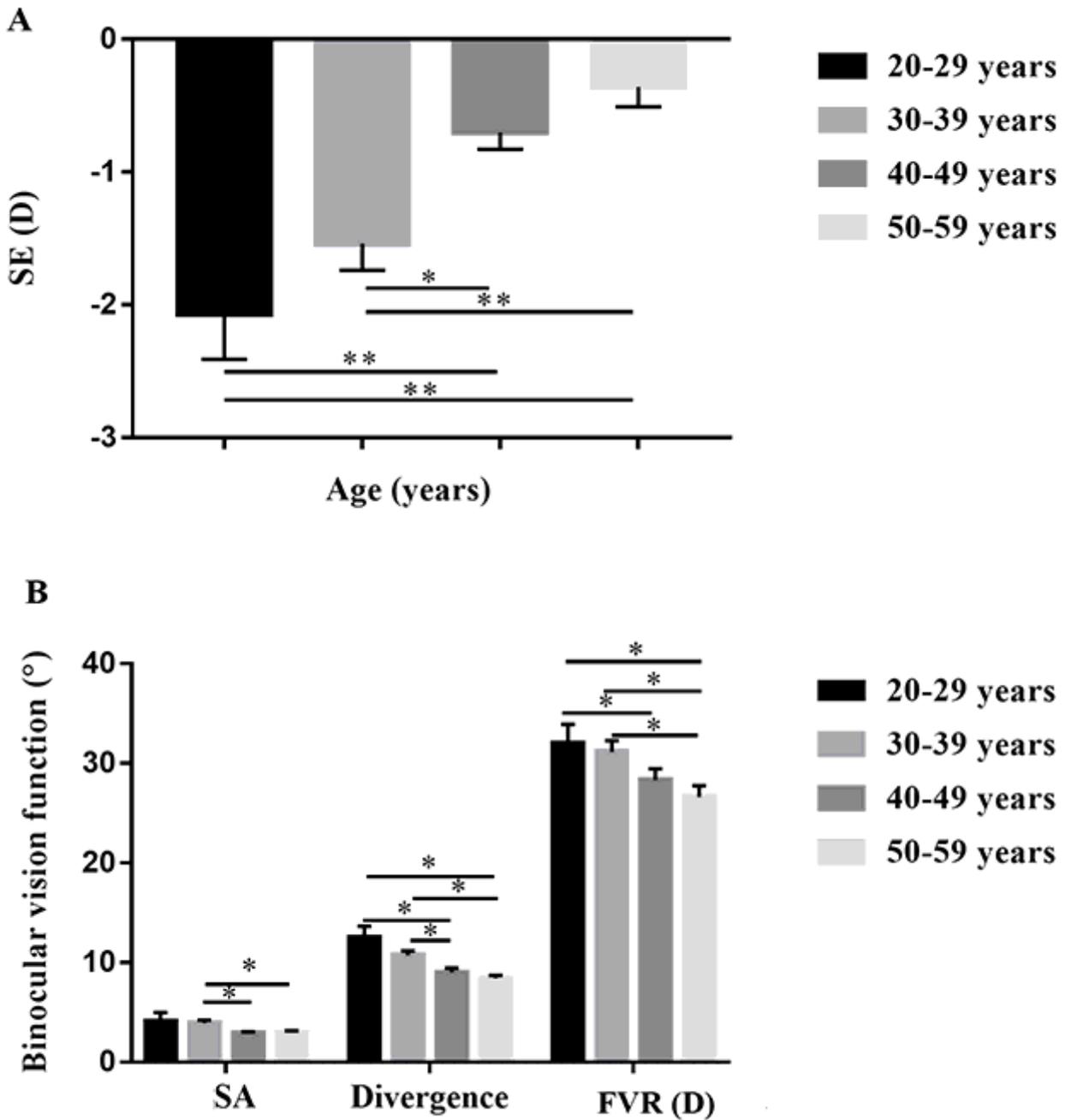
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The relationship between SE with subjective squint angle and divergence, (A) SSA and SE, (B) divergence and SE. The mean age was  $42.1 \pm 0.61$  years, ranging from 20-59 years. SA, subjective squint angle, SE, spherical equivalent.



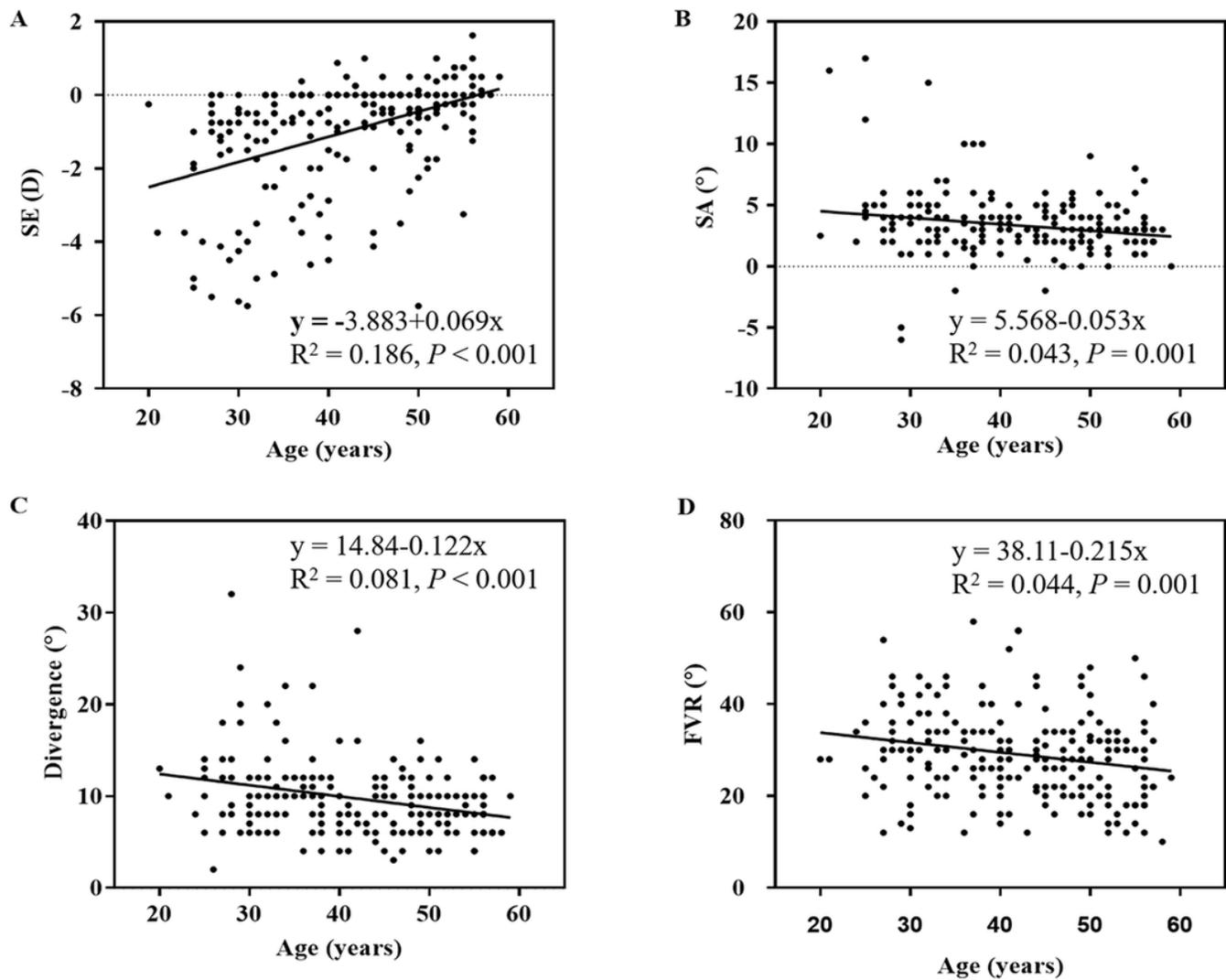
**Figure 2**

Comparisons of SE and binocular visual function among different age groups, (A) SE in different age groups, (B) SA, divergence, range of fusion in different age groups. \* represent significant differences between two groups (\*\* $p < 0.01$ , \* $p < 0.05$ ). SA, subjective squint angle. SE, spherical equivalent.



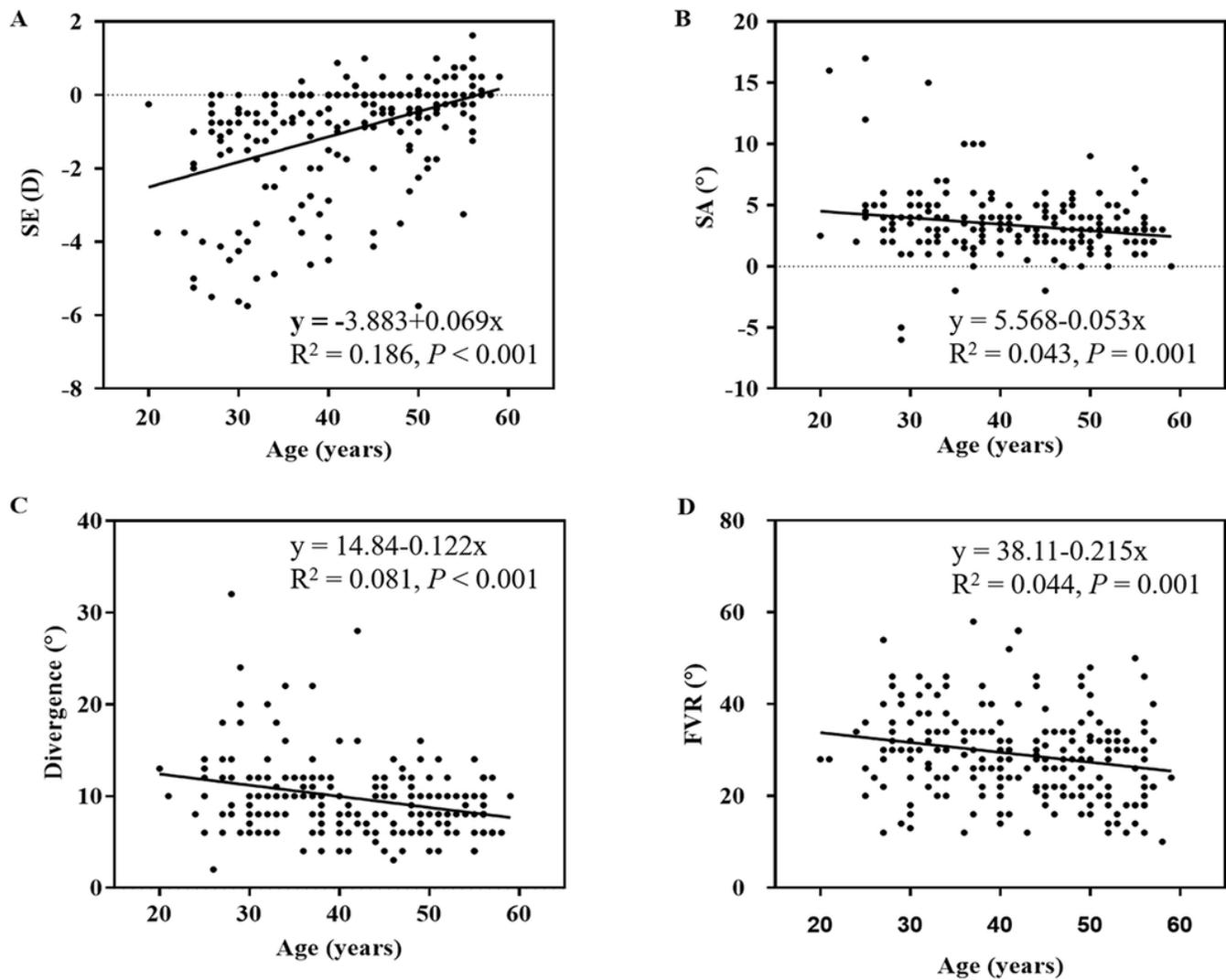
**Figure 2**

Comparisons of SE and binocular visual function among different age groups, (A) SE in different age groups, (B) SA, divergence, range of fusion in different age groups. \* represent significant differences between two groups (\*\* $p < 0.01$ , \* $p < 0.05$ ). SA, subjective squint angle. SE, spherical equivalent.



**Figure 3**

The relationship between age with SE, subjective squint angle, divergence and range of fusion, (A) SE and age, (B) SA and age, (C) divergence and age, (D) range of fusion and age. The mean age was  $42.1 \pm 0.61$  years, ranging from 20-59 years. SA, subjective squint angle. SE, spherical equivalent.



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