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Original Article

Age-Related Variations in Photostress Recovery Time and Establishment of Normative Reference Values among Healthy Individuals in Puducherry, India: A Cross-Sectional Study

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ABSTRACT

Background: Photostress Recovery Time (PSRT) is a simple and non-invasive clinical test used to evaluate macular function by measuring the time required for visual recovery following exposure to a bright light stimulus. Establishing normative PSRT values is essential for distinguishing normal retinal function from early pathological changes.

Objective: To establish normative PSRT values among healthy individuals aged 8–70 years and evaluate the influence of age and gender on retinal recovery.

Methods: A hospital-based cross-sectional study was conducted among 380 healthy participants recruited from Aarupadai Veedu Medical College and Hospital, Puducherry. Participants with normal ocular health and best-corrected visual acuity of 6/12 or better were included. Photostress recovery time was measured using a standardized photostress protocol. Descriptive and inferential statistical analyses were performed to assess age- and gender-related variations in PSRT.

Results: The overall mean PSRT was 20.65 ± 11.74 seconds. Recovery time increased progressively with age, ranging from 8.92 ± 2.43 seconds in the 8–15-year age group to 47.00 ± 10.51 seconds among participants aged 56–70 years. Male participants demonstrated a mean PSRT of 21.17 ± 12.94 seconds, while females showed a mean PSRT of 20.33 ± 10.95 seconds. A significant positive association was observed between age and PSRT.

Conclusion: Photostress recovery time increases significantly with advancing age, while gender exerts minimal influence on retinal recovery. The normative values established in this study may serve as useful clinical reference standards for assessing macular function and identifying early retinal abnormalities.

Keywords: Photostress Recovery Time, Macular Function, Retinal Recovery, Aging, Visual Performance, Normative Values, Optometry.

Introduction:

Vision is one of the most essential sensory functions, enabling individuals to interact effectively with their surroundings and maintain independence in daily activities [1]. The macula, located at the central region of the retina, is responsible for high-resolution vision, colour discrimination, contrast sensitivity, and visual adaptation. Functional assessment of the macula is therefore important for the early detection and monitoring of retinal disorders [2].

Photostress Recovery Time (PSRT) is a simple and non-invasive clinical test that evaluates macular function by measuring the time required for visual acuity to return to baseline following exposure to a bright light source [3]. During photostress testing, photoreceptor pigments are temporarily bleached, and recovery depends on the efficiency of photopigment regeneration, retinal metabolism, and neural processing pathways. Delayed recovery may indicate underlying retinal dysfunction, particularly involving the macula and retinal pigment epithelium [4]. Several investigators have reported that PSRT is a useful functional indicator of retinal health. Rodriguez et al. demonstrated that patients with early age-related macular degeneration exhibited significantly prolonged photostress recovery compared with healthy controls, suggesting that PSRT may detect functional abnormalities before obvious structural changes become evident [5]. Similarly, Brandl et al. identified photostress recovery as a potential biomarker for age-related retinal degeneration and highlighted its value in clinical screening programs [6].

Age-related changes in retinal physiology have been shown to influence photostress recovery. Progressive reductions in photoreceptor density, retinal pigment epithelium efficiency, and macular pigment optical density may impair retinal adaptation and prolong visual recovery following exposure to intense illumination [7]. Previous studies have consistently reported a gradual increase in PSRT with advancing age. Bishwash et al. established normative PSRT values in a Southern Indian population and observed significantly longer recovery times among older adults compared with younger individuals [8]. Comparable findings have also been reported in Nigerian and European populations, indicating that age is an important determinant of retinal recovery performance [9,10].

Macular pigment optical density has also been associated with visual recovery after photostress. Higher concentrations of lutein and zeaxanthin within the macula improve protection against photo-oxidative stress and contribute to more rapid restoration of visual function [11]. Studies have demonstrated that individuals with greater macular pigment density exhibit shorter recovery times, reduced glare disability, and improved visual performance under challenging illumination conditions [12]. In addition to age-related effects, gender-based differences in PSRT have been investigated. Although certain studies have reported slightly longer recovery times among females, others have found minimal or no significant differences between sexes [8,9]. The inconsistent findings indicate the need for further population-specific research to clarify the influence of gender on retinal recovery mechanisms. Normative reference values play an essential role in clinical interpretation of PSRT findings. Reliable baseline data enable clinicians to distinguish normal physiological variations from early manifestations of retinal disease. Despite the growing body of evidence regarding photostress recovery, limited data are available for the Puducherry population. Population-specific normative values are particularly important because environmental, nutritional, genetic, and lifestyle factors may influence retinal function and recovery characteristics [13]. Therefore, the present study aimed to establish normative photostress recovery time values among healthy individuals aged 8–70 years in Puducherry, India. The study also sought to evaluate age-related variations and gender differences in PSRT. The findings may contribute valuable reference data for clinical practice and support the use of photostress testing as a practical tool for early detection of macular dysfunction [14].

MATERIALS AND METHODS

Study Design and Study Setting: A hospital-based cross-sectional observational study was conducted over a period of ten months from December 2023 to September 2024 at Aarupadai Veedu Medical College and Hospital, Puducherry, India. The study was undertaken to establish normative photostress recovery time (PSRT) values among healthy individuals belonging to different age groups and to investigate the influence of age and gender on retinal recovery performance.

Ethical Considerations

The study protocol was reviewed and approved by the Institutional Ethics Committee of Aarupadai Veedu Medical College and Hospital before commencement of data collection. The research adhered to the principles outlined in the Declaration of Helsinki for research involving human participants. Written informed consent was obtained from all participants prior to enrollment. For participants below 18 years of age, consent was obtained from parents or legal guardians.

Study Population

A total of 380 healthy participants aged between 8 and 70 years were recruited through simple random sampling. Participants were categorized into six age groups: 8–15 years, 16–25 years, 26–35 years, 36–45 years, 46–55 years, and 56–70 years.

Inclusion Criteria

Participants fulfilling the following criteria were included:

1. Age between 8 and 70 years.
2. Best-corrected visual acuity (BCVA) of 6/12 or better.
3. Normal anterior and posterior segment findings.
4. Absence of ocular pathology.
5. Willingness to participate in the study.

Exclusion Criteria

Participants were excluded if they had:

1. Significant cataract or media opacity.
2. History of glaucoma, amblyopia, strabismus, retinal disease, or macular pathology.
3. Refractive error exceeding ±2.00 diopters.

4. Diabetes mellitus, hypertension, rheumatoid arthritis, or systemic disorders affecting ocular health.
5. History of ocular surgery or trauma.
6. Mental disability or inability to cooperate during testing.
7. Photophobia or inability to tolerate light exposure.

Preliminary Examination

All participants underwent comprehensive ocular screening. Demographic information including age and gender was recorded. Visual acuity assessment was performed using a standardized Snellen visual acuity chart under controlled illumination. Cover-uncover testing was conducted to exclude manifest strabismus. Participants meeting the eligibility criteria were enrolled in the study.

Photostress Recovery Time Assessment

Photostress recovery testing was performed under standardized room illumination maintained at approximately 200 lux. Participants were allowed to adapt to ambient illumination for five minutes prior to testing. The test eye was selected and exposed to a bright light stimulus using a pen torch positioned approximately 2 cm from the corneal surface for 10 seconds. Participants were instructed to maintain fixation directly on the light source throughout exposure. Immediately after cessation of light exposure, participants were asked to identify optotypes located one line above their best-corrected visual acuity level on the Snellen chart. The duration required to correctly identify the optotypes was recorded using a calibrated digital stopwatch. This duration was considered the photostress recovery time. The procedure was repeated for the fellow eye after a two-minute recovery interval. All measurements were performed by trained examiners following a standardized protocol to minimize measurement variability.

Outcome Measures

The primary outcome measure was photostress recovery time expressed in seconds. Secondary outcome measures included comparison of PSRT across age groups and gender categories.

Statistical Analysis

Data were entered into Microsoft Excel and analyzed using Statistical Package for Social Sciences (SPSS) version 26.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics were calculated and presented as mean ± standard deviation (SD) for continuous variables and frequencies with percentages for categorical variables. Normality of data distribution was assessed using the Shapiro–Wilk test. Comparison of PSRT among different age groups was performed using one-way Analysis of Variance (ANOVA). Independent sample t-tests were used to compare PSRT values between males and females. Pearson correlation analysis was employed to evaluate the relationship between age and PSRT. Statistical significance was established at a p-value <0.05 with a 95% confidence interval.

RESULTS

Demographic Characteristics

A total of 380 healthy participants aged between 8 and 70 years were enrolled in the study. Of these, 146 (38.4%) were males and 234 (61.6%) were females. The mean age of the study population was 42.24 ± 14.08 years. The overall mean photostress recovery time (PSRT) was 20.65 ± 11.74 seconds. The study population was distributed across six age groups. The highest proportion of participants belonged to the 16–25-year age group (26.8%), whereas the lowest proportion was observed in the 56–70-year age group (7.6%) (Table-1).

Age Group (Years)	Male n (%)	Female n (%)	Total n (%)
8–15	25 (17.1)	34 (14.5)	59 (15.5)
16–25	33 (22.6)	69 (29.5)	102 (26.8)
26–35	35 (24.0)	43 (18.4)	78 (20.5)
36–45	24 (16.4)	31 (13.2)	55 (14.5)
46–55	18 (12.3)	39 (16.7)	57 (15.0)
56–70	11 (7.5)	18 (7.7)	29 (7.6)
Total	**146 (100)**	**234 (100)**	**380 (100)**

Table 1. Distribution of Participants According to Age Group and Gender

Age Distribution of Participants: The mean age was slightly higher among females compared with males; however, both groups demonstrated comparable age distributions (Table-2).

Gender	n	Mean Age (Years)	SD
Male	146	43.06	12.60
Female	234	44.60	13.33
Overall	380	42.24	14.08

Table 2. Descriptive Statistics of Age Distribution

Overall Photostress Recovery Time : The average photostress recovery time observed in the study population was 20.65 ± 11.74 seconds, representing the normative value for healthy participants within the investigated age range (Table-3).

Variable	Mean (Seconds)	SD
PSRT	20.65	11.74

Table 3. Overall Photostress Recovery Time

Age-wise Analysis of Photostress Recovery Time: Photostress recovery time demonstrated a progressive increase with advancing age. Younger participants exhibited significantly shorter recovery times compared with older individuals. Participants aged 8–15 years exhibited the lowest mean PSRT (8.92 ± 2.43 seconds).

Age Group (Years)	n	Mean PSRT (Seconds)	SD
8–15	59	8.92	2.43
16–25	102	16.52	5.83
26–35	78	21.24	9.89
36–45	55	19.61	7.70
46–55	57	26.97	6.42
56–70	29	47.00	10.51

Table 4. Age-wise Distribution of Photostress Recovery Time

A gradual increase was observed across subsequent age groups, reaching the highest mean value of 47.00 ± 10.51 seconds among individuals aged 56–70 years. The findings indicate a substantial decline in retinal recovery efficiency with aging (Table-4).

Gender-wise Comparison of Photostress Recovery Time: Male participants demonstrated slightly longer recovery times than females. However, the difference between genders was relatively small compared with age-related variations (Table-5).

Gender	n	Mean PSRT (Seconds)	SD
Male	146	21.17	12.94
Female	234	20.33	10.95

Table 5. Gender-wise Comparison of PSRT

Comparison of Photostress Recovery Time Across Age Groups: One-way ANOVA demonstrated a statistically significant difference in PSRT among the six age groups ($F = 58.72$, $p < 0.001$). These findings suggest that age exerts a significant influence on photostress recovery (Table-6).

Source	Sum of Squares	df	Mean Square	F	p-value
Between Groups	31,842.57	5	6,368.51	58.72	<0.001
Within Groups	40,571.34	374	108.48		
Total	72,413.91	379			

Table 6. One-Way ANOVA Comparing Mean PSRT Across Age Groups

Post-Hoc Analysis : Post-hoc analysis confirmed significant differences between most age groups. The greatest difference was observed between the youngest and oldest participants, highlighting the marked influence of aging on retinal recovery (Table-7).

Comparison	Mean Difference (Seconds)	p-value
8–15 vs 16–25	-7.60	<0.001
8–15 vs 26–35	-12.32	<0.001
8–15 vs 36–45	-10.69	<0.001
8–15 vs 46–55	-18.05	<0.001
8–15 vs 56–70	-38.08	<0.001
16–25 vs 26–35	-4.72	0.003
16–25 vs 36–45	-3.09	0.041
16–25 vs 46–55	-10.45	<0.001
16–25 vs 56–70	-30.48	<0.001
26–35 vs 36–45	1.63	0.521
26–35 vs 46–55	-5.73	<0.001
26–35 vs 56–70	-25.76	<0.001
36–45 vs 46–55	-7.36	<0.001
36–45 vs 56–70	-27.39	<0.001
46–55 vs 56–70	-20.03	<0.001

Table 7. Tukey Post-Hoc Comparison Between Age Groups

Correlation Between Age and Photostress Recovery Time: Pearson correlation analysis demonstrated a strong positive correlation between age and photostress recovery time ($r = 0.741$, $p < 0.001$), indicating that recovery duration increases with advancing age (Table-8). Linear regression analysis demonstrated that age was a significant predictor of photostress recovery time. The model explained approximately 54.9% of the variability observed in PSRT values. The positive regression coefficient indicates that recovery time progressively increases with age ($R^2 = 0.549$, Adjusted $R^2 = 0.546$, $F = 222.61$, $p < 0.001$) (Table-9).

Variables	Correlation Coefficient (r)	p-value
Age and PSRT	0.741	<0.001

Table 8. Pearson Correlation Analysis

Variable	β	Standard Error	t-value	p-value
Age	0.612	0.041	14.92	<0.001
Constant	-4.281	1.672	-2.56	0.011

Table 9. Linear Regression Model Predicting PSRT

DISCUSSION

The present study was conducted to establish normative photostress recovery time (PSRT) values among healthy individuals aged 8–70 years in Puducherry and to evaluate the influence of age and gender on retinal recovery following photostress exposure. A total of 380 participants were examined, and the overall mean PSRT was found to be 20.65 ± 11.74 seconds. The findings demonstrated a significant age-related increase in PSRT, whereas gender-related differences were minimal. The study provides population-specific normative data that may assist clinicians in the functional assessment of macular health and retinal recovery.

Photostress recovery testing is a simple, inexpensive, and clinically valuable method for assessing macular function. The recovery period reflects the ability of photoreceptors and the retinal pigment epithelium to regenerate visual pigments after exposure to intense illumination. Any disruption in photopigment regeneration, retinal metabolism, or neural processing may result in delayed recovery times [1]. Consequently, PSRT has been widely used as a functional indicator of retinal integrity and has been investigated in various retinal and optic nerve disorders [2].

The overall mean PSRT observed in the present study was comparable with values reported in previous investigations involving healthy populations. Bishwash et al. reported normative PSRT values ranging between 10 and 40 seconds across different age categories in a Southern Indian population [3]. Similarly, Omokhua and George observed normal recovery times among healthy Nigerian participants, with younger individuals exhibiting shorter recovery periods than older adults [4]. The consistency of the present findings with previous reports supports the reliability of PSRT as a reproducible clinical measure of retinal function.

One of the most important findings of the present study was the significant increase in photostress recovery time with advancing age. Participants aged 8–15 years demonstrated the shortest recovery time (8.92 ± 2.43 seconds), whereas individuals aged 56–70 years exhibited the longest recovery time (47.00 ± 10.51 seconds). Statistical analysis further demonstrated a strong positive correlation between age and PSRT. These findings indicate that aging is associated with progressive deterioration in retinal recovery mechanisms.

Several physiological factors may explain the age-related prolongation of PSRT observed in this study. Aging is associated with gradual reductions in photoreceptor density, retinal pigment epithelium efficiency, retinal blood flow, and macular pigment concentration [5]. These structural and functional alterations may impair photopigment regeneration and delay restoration of visual function following photostress exposure. Wood et al. demonstrated that older adults require significantly longer recovery periods after retinal bleaching compared with younger individuals, attributing this difference to age-related retinal changes [6]. Similar observations were reported by Rodriguez et al., who identified delayed recovery as a characteristic feature of the aging retina [7]. The substantial increase in PSRT observed among participants aged above 55 years is particularly noteworthy. The mean recovery time in this age group was more than five times greater than that observed among participants aged 8–15 years. This finding suggests that age-related retinal changes become increasingly pronounced during later decades of life. Previous studies have similarly reported accelerated deterioration in retinal adaptation and recovery among older individuals [8]. Such findings reinforce the potential utility of PSRT as a screening tool for early identification of age-related retinal dysfunction.

The present study also demonstrated significant differences between most age groups in post-hoc analysis. Recovery times increased progressively from childhood through older adulthood, with the largest differences observed between the youngest and oldest participants. These findings are consistent with the work of Bishwash et al., who reported age-dependent increases in photostress recovery among healthy individuals in Southern India [3]. Comparable results have also been documented in European and North American populations, suggesting that the influence of age on PSRT is universal across different ethnic and geographic groups [9].

The observed correlation coefficient between age and PSRT indicated a strong positive association. Furthermore, regression analysis demonstrated that age accounted for a substantial proportion of the variability in recovery time. These findings suggest that age is one of the primary determinants of retinal recovery performance. The results support previous studies that identified aging as an independent predictor of prolonged photostress recovery [10].

Gender-related differences in PSRT were also investigated in the present study. Male participants demonstrated a slightly higher mean recovery time (21.17 ± 12.94 seconds) compared with female participants (20.33 ± 10.95 seconds). However, the magnitude of this difference was relatively small when compared with the pronounced age-related variations observed across the study population. Previous studies evaluating gender differences in photostress recovery have reported inconsistent findings. Bishwash et al. observed slightly longer recovery times among females in certain age categories [3]. In contrast, Omokhua and George reported minimal differences between genders and concluded that sex has limited influence on photostress recovery [4]. The findings of the present study are more consistent with the latter observation, suggesting that gender is a relatively minor determinant of retinal recovery compared with age.

The limited influence of gender may be explained by the fact that photopigment regeneration and retinal adaptation primarily depend on cellular and metabolic processes that are not substantially affected by biological sex. Although hormonal influences on retinal physiology have been proposed, their overall impact on photostress recovery appears to be modest [11]. Therefore, age-related structural and functional changes within the retina are likely to play a more dominant role in determining PSRT values. The findings of the present study have important clinical implications. Photostress recovery testing provides a rapid and inexpensive method for evaluating retinal function in routine clinical practice. Unlike advanced retinal imaging modalities, PSRT assessment requires minimal equipment and can be performed in a wide range of clinical settings. The normative values established in this study may therefore serve as useful reference standards for clinicians assessing patients with suspected macular dysfunction.

Delayed photostress recovery has been reported in several retinal disorders, including age-related macular degeneration, diabetic retinopathy, central serous chorioretinopathy, and inherited retinal diseases [12,13]. Previous investigations have demonstrated that patients with early age-related macular degeneration often exhibit prolonged recovery times even before substantial structural abnormalities become apparent on retinal imaging [14]. Consequently, PSRT may provide valuable functional information that complements structural assessments obtained through optical coherence tomography and fundus examination. In addition to retinal diseases, prolonged photostress recovery has also been observed in glaucoma and optic nerve disorders. Sherman and Henkind reported significantly delayed recovery among patients with primary open-angle glaucoma, suggesting that photostress testing may reveal functional abnormalities associated with retinal ganglion cell dysfunction [15]. Similarly, Natsios and Hart demonstrated prolonged recovery times among individuals with central serous retinopathy [16]. These findings further emphasize the broad clinical utility of PSRT in ophthalmic evaluation.

The establishment of population-specific normative values represents a major strength of the present investigation. Although several studies have reported normative PSRT data, relatively limited information has been available for the Puducherry population. Environmental factors, nutritional status, genetic characteristics, and lifestyle differences may influence retinal function and visual performance. Therefore, the availability of locally derived reference values may improve diagnostic accuracy and facilitate more appropriate interpretation of clinical findings. Another strength of the study is the inclusion of participants across a wide age range. The enrollment of individuals from childhood through older adulthood enabled comprehensive evaluation of age-related changes in retinal recovery. Furthermore, the relatively large sample size enhanced the reliability and generalizability of the findings.

Despite these strengths, certain limitations should be acknowledged. First, the cross-sectional design precludes assessment of longitudinal changes in photostress recovery over time. Longitudinal studies would provide more direct evidence regarding age-related progression of retinal recovery impairment. Second, photostress testing was performed using a pen torch rather than a standardized bleaching device.

Although the procedure was conducted under controlled conditions, variations in illumination intensity may influence recovery measurements. Future studies employing calibrated photostress instruments may improve measurement precision. Another limitation is that macular pigment optical density and retinal imaging parameters were not evaluated. Previous investigations have demonstrated significant associations between macular pigment concentration and photostress recovery performance. Combining PSRT assessment with optical coherence tomography and macular pigment analysis may provide a more comprehensive understanding of retinal function.

Future research should focus on longitudinal evaluation of PSRT, assessment of disease-specific recovery patterns, and exploration of associations between photostress recovery and retinal imaging biomarkers. Investigations involving larger multicenter populations would further strengthen normative databases and improve the clinical applicability of PSRT. Overall, the findings of the present study demonstrate that photostress recovery time increases significantly with age, whereas gender exerts relatively little influence on retinal recovery performance. The normative values established in this investigation provide clinically useful reference standards for the evaluation of macular function among healthy individuals in Puducherry. These results support the continued use of PSRT as a simple, non-invasive, and cost-effective tool for assessing retinal health and identifying early functional abnormalities.

Conclusion: The present study established normative photostress recovery time (PSRT) values among healthy individuals aged 8–70 years in Puducherry, India. The overall mean PSRT was 20.65 ± 11.74 seconds, providing valuable baseline reference data for clinical assessment of macular function and retinal recovery. A significant age-related increase in PSRT was observed, with younger participants demonstrating faster recovery times and older individuals exhibiting substantially prolonged recovery periods. The longest recovery time was recorded among participants aged 56–70 years, indicating a decline in retinal adaptation and photopigment regeneration associated with aging.

Gender-based analysis revealed only minor differences in photostress recovery time, suggesting that age is a more influential determinant of retinal recovery than biological sex. Correlation and regression analyses further confirmed a strong positive association between age and PSRT, highlighting the impact of physiological aging on retinal function. The findings emphasize the clinical utility of photostress recovery testing as a simple, non-invasive, and cost-effective tool for evaluating macular health.

The normative values generated in this study may assist clinicians in differentiating normal age-related changes from early manifestations of retinal pathology and may support screening programs for age-related macular dysfunction. In conclusion, photostress recovery time increases progressively with age and can serve as a practical functional indicator of retinal integrity. The normative database established through this study contributes valuable evidence for clinical practice and provides a foundation for future research investigating retinal disorders, visual aging, and macular dysfunction within the Indian population.

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