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ORIGINAL ARTICLE

Effect of defocus on response time in different age groups: A pilot study

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KEYWORDS
Presbyopia;
Reaction time;
Defocus

Abstract
Purpose: To assess the response time associated with visual performance (VP) tasks in the presence of defocus in different presbyopic populations.
Methods: 58 eyes between the ages of 35 and 50 years were studied. Subjects were categorized as pre-presbyopic (35–39 years), early-presbyopic (40–45 years), and mid-presbyopic (46–50 years). VP measurements obtained monocularly included distance and near high contrast (HC) and low contrast (LC) optotype recognition, and contrast threshold at 12 cpd for different defocus magnitudes between 0D and 3D in 1D steps. Response time defined as the time taken to recognize and verbalize an optotype, was compared among different presbyopic age groups.
Results: From 58 eyes, mean (SD) response time for high contrast distance visual acuity for 0D through 3D ranged between 1.48 (0.23) and 1.87 (0.31) s, whereas low contrast distance visual acuity ranged between 1.5 (0.22) and 2.09 (0.49) s. Mean response time for high contrast near visual acuity for 0D through 3D ranged between 1.56 (0.19) and 2.23 (0.45) s. However, for low contrast near visual acuity it ranged between 1.75 (0.32) and 2.71 (0.94) s. Mean (SD) response time for 12 cpd ranged between 2.11 (0.50) and 5.72 (1.09) s. ANOVA revealed a significant difference in response time for distance, near visual acuity and contrast sensitivity as a function of defocus for different age groups.
Conclusions: Response time is increased in the presence of increasing defocus for both distance and near visual acuity and could impact on performance for critical tasks. Full correction of visual acuity at distance and near in presbyopes is warranted always.

PALABRAS CLAVE
Presbicia;
Tiempo de reacción;
Desenfoque

Efecto del desenfoque en el tiempo de respuesta en diferentes grupos de edad: estudio piloto

Resumen
Objetivo: Evaluar el tiempo de respuesta asociado a las tareas del desempeño visual (DV) en presencia de desenfoque, en diferentes poblaciones présbitas.

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Métodos: Se estudiaron 58 ojos de personas en edades comprendidas entre 35 y 50 años. Se clasificó a los sujetos conforme a las siguientes categorías: pre-presbicia (35−39 años), presbicia temprana (40−45 años), y presbicia media (46−50 años). Las mediciones del desempeño visual obtenidas de forma monocular incluyeron el reconocimiento de optotipos cercanos y lejanos de alto y bajo contraste y el umbral de contraste a 12cpd para las diferentes magnitudes de desenfoque, entre 0D y 3D, a intervalos de 1D. El tiempo de respuesta es el tiempo empleado en reconocer y verbalizar un optotipo, y se comparó entre los diferentes grupos de edad de los individuos présbitas.
Resultados: De los 58 ojos, el tiempo de respuesta media (DE) para la agudeza visual de la distancia a alto contraste, entre 0D y 3D, osciló entre 1,48 (0,23) y 1,87 (0,31) segundos, mientras que la agudeza visual de la distancia a bajo contraste osciló entre 1,5 (0,22) y 2,09 (0,49) segundos. El tiempo de respuesta media para la agudeza visual cercana de alto contraste entre 0D y 3D osciló entre 1,56 (0,19) y 2,23 (0,45) segundos. Sin embargo para la agudeza visual cercana de bajo contraste osciló entre 1,75 (0,32) y 2,71 (0,94) segundos. El tiempo de respuesta media (DE) para 12cpd osciló entre 2,11 (0,50) y 5,72 (1,09) segundos. ANOVA reveló una diferencia significativa en cuanto al tiempo de respuesta para la distancia, agudeza visual cercana y sensibilidad de contraste como función del desenfoque para los diferentes grupos de edad.
Conclusiones: El tiempo de respuesta se eleva al incrementarse el desenfoque en la agudeza visual lejana y cercana, pudiendo repercutir sobre el desempeño de ciertas tareas esenciales. La corrección plena de la agudeza visual cercana y lejana en individuos présbitas debe de ser siempre garantizada.

Introduction

By 2020, an estimated 1.4 billion people will be affected by presbyopia.[1] Uncorrected refractive error is the leading cause of visual impairment in adults over the age of 40 years,[2] with the prevalence of refractive visual impairment increasing significantly with age.[3] However, uncorrected presbyopes are at a bigger disadvantage. Presbyopia refers to the slow, normal, naturally occurring, age-related, irreversible reduction in maximal accommodative amplitude sufficient to cause symptoms of blur and ocular discomfort or asthenopia at the customary nearworking distance.[4] The exact mechanism of presbyopia is not well understood. Prior research suggests a loss of elasticity of the crystalline lens, although changes in the lens's curvature from loss of ciliary muscle function have also been proposed as its cause.[4] As one ages to presbyopia, there is a progressive change in the optics of the eye[5] with the possibility of an increase in the optical aberrations.[4,5] In addition, the oculomotor components that decrease with age include amplitude of accommodation, tonic accommodation, CA/C ratio, as well as positive and negative fusional vergence recovery values at distance.[6] In contrast, the components that increase in magnitude with presbyopia include: subjective depth of focus, accommodative latency, disparity vergence, etc.[6] These changes play a very important role in both spatial and temporal visual information processing. Hence, age related decline in visual function will be observed in all adults.

The first signs of presbyopia include eyestrain, difficulty in seeing in dim light, problems focusing on small objects and/or fine print and are usually first noticed between the ages of 35 and 40 years.[7] Visual acuity[8] and contrast sensitivity[9] is degraded in the presence of blur. When dioptric blur is introduced it also alters the background luminance. Legge et al.[10] reported on the various stimulus factors that influenced reading speed and found that diffusive blur was one such factor. Later, Johnson and Casson[11] studied the interactions of luminance, contrast and blur on visual acuity. They reported that the visual acuity is reduced in the presence of blur levels up to 2D and a gradual decrease occurs with higher levels of blur. Thorn and Thorn[12] studied the effect of induced blur on reading accuracy of television captions and reported that blur and fast presentation rate reduced reading speed dramatically. So, blurring of the visual system does impact any visual performance task.

While visual acuity is the most commonly used clinical metric to assess vision, contrast sensitivity function (CSF) provides a more comprehensive assessment and serves as the building block for the succeeding steps of visual information processing.

Blur typically increases during presbyopia with a progressive deterioration in the clinically measured visual acuity during the same period.[13] While plus lenses are prescribed for 2-months to alleviate the symptoms associated with presbyopia, a recent investigation[14] reported that after a period of wearing near vision glasses, three metrics of the accommodative convergence function, namely, the slope of the stimulus response function and the accommodative convergence/accommodation (AC/A) and convergent accommodation/convergence (CA/C) ratios did not change significantly. In addition, a hyperopic shift of the stimulus response function was also reported thereby reducing the far-point refraction. There were no age-related changes with these components. Visual acuity and contrast sensitivity of uncorrected presbyopes decrease at near due to lack of inherent accommodative response. In addition, the deterioration in the optics of the eye makes the high spatial frequency component of optotypes in vision testing appear dimmer, thereby lowering the visual acuity and contrast sensitivity threshold.[4] Recent study by Chung et al.[15] on 19 normal young subjects aged investigated the reading speed with MNREAD charts in the presence of defocus of 0, 0.5, 1, 2 and 3D. They reported that the reading speed was minimally affected by smaller magnitudes of blur and was ∼23% slower with 3D of blur. Thus, only for larger magnitudes of blur, reading speed is decreased. This investigation involved measurements under cycloplegic conditions with convex lenses and artificial pupil size of 3 mm. While this study reported the effect of defocus on reading speed, no age-related effects were reported that significantly impacted reading time. More recently, Polat[16] had investigated the effect of training presbyopes with perceptual learning using contrast detection of a Gabor target. Training involved two sessions a week with target presentations of various spatial frequencies and orientations. Visual acuity, spatial and temporal contrast sensitivity and response times were assessed pre- and post-training. This study performed on older subjects (50 ± 1.1 years of age) reported that there was an improvement in distance and near visual acuity and contrast sensitivity. In addition, a subjective improvement was also noticed. Hence, presbyopes can be trained to improve visual performance.

There is a lack of information regarding visual processing and a change in response time as one ages into presbyopia. Thus, the aim of the current study was to assess the response time to clear defocus of different magnitudes in pre-presbyopic and presbyopic age groups for different visual performance tasks.

Methods

Subjects were categorized based on age into three different groups: pre-presbyopic: 35–39 ($n = 18$), early-presbyopic: 40–45 ($n = 18$), and mid-presbyopic: 46–50 ($n = 22$) years. Amplitude of accommodation was measured for each group to make sure that subjects belonging to each group had similar amplitude. Exclusion criteria for this study included: anyone over the age of 50 years to exclude any senile changes that may skew the results, patients with greater than 0.75 diopters of cylinder, ocular or systemic pathologies, and those with lenticular changes. In addition, any potential subject with history of ocular, systemic or neurological disease was excluded from the study. Subjects were enquired of the same during the screening visit. All the subjects were screened for the presence of lenticular changes with aging and anyone with lenticular changes and/or visual acuity of 20/30 or less with habitual correction at distance or near were also excluded. Consent was obtained from all the subjects prior to the participation in the study. The study protocol was approved by the Midwestern University IRB committee. The research adhered to the tenets of the Declaration of Helsinki.

Objective open-field (WAM-5500, Shin Nippon, AIT Industries, IL) followed by subjective refraction was performed on all the subjects by an experienced optometrist to measure the refractive error. Subjects' refraction ranged between −3D and +1D.

A structured testing regimen was used to assess the response times of all age groups with various levels of defocus. The testing procedures included logMAR high and low contrast visual acuity at distance and near, and contrast threshold at 12 cpd (CSV-1000; VectorVision, Greenville, OH). Baseline best corrected logMAR visual acuity and response times were recorded with targets at both 6 m and 40 cm. Baseline contrast sensitivity and their respective response times at a test distance of 10 ft were recorded as well. Response time is defined as the magnitude of time it takes for the subject to clearly see a specific acuity level, i.e., identify the individual letter and state it aloud. A total of three measurements were taken for each procedure and then averaged. A brief introduction and training session was performed on each subject to compensate for any learning curve to the procedures performed. The same experimenter measured response time to avoid any variability. The individual subject sessions lasted for, on average, approximately 45 min. Following baseline measurement, visual acuity and contrast sensitivity were measured for different defocus levels of 0D, 1D, 2D and 3D, respectively. All the testing procedures were completed in one visit. Subjects were given sufficient time breaks in between measurements to avoid any fatigue related effects.

This study utilized defocusing an image by introducing a concave lens in front of the test subject while best corrected for distance and near. The test subject was first instructed to close their eyes, and then asked to open them at the examiner's request. This was done to ensure an accurate response time assessment starting point. A single optotype was isolated prior to the test subject opening their eyes at the specific distance for each test stated above. Three different hand-held flipper lenses of powers 0, −1.00, −2.00, −3.00D were introduced at the spectacle plane of the patient, one at a time. Defocus was introduced randomly and a very short rest period of a few minutes was provided in between the measurements of response time with defocus. Utilizing a precision timer device that can measure time with a millisecond resolution, the examiner started the timer at the exact moment the patient was instructed to open their eyes, and stopped the timer as soon as the letter was read aloud by the subject. This procedure was performed three different times with each defocus lens, and the average value was used for the results to improve the reliability. A practice trial session was also performed at the beginning with a plano lens. Response time describes the amount of time taken to recognize and verbalize a single optotype that was presented to the subject for a given magnitude of defocus. The optotype chosen was one line above their visual acuity for both distance and near. Surrounding optotypes were blocked to avoid any distraction. The same investigator measured response times for all the subjects and was not aware of the subjects' age.

The visual acuity and average response times were recorded for distance (6 m), and near (40 cm), for both high and low contrast targets (10% contrast level), using logMAR visual acuity at distance (ETDRS chart) and an acuity card at near (Precision Vision, La Selle, IL). All the measured response times were obtained either from the left or right eye randomly. Similar procedure was utilized for contrast

Table 1 Summary of mean (SD) response time for distance and near visual acuity at low and high contrast in the presence of different defocus levels. DVA HC, distance visual acuity with high contrast; LC, low contrast; NVA, near visual acuity.

Age (years)	Defocus (D)	DVA HC	DVA LC	NVA HC	NVA LC
35–40	0	1.48 (0.23)	1.50 (0.22)	1.56 (0.19)	1.75 (0.32)
41–45	0	1.63 (0.31)	1.71 (0.4)	1.80 (0.39)	2.04 (0.45)
46–50	0	1.62 (0.22)	1.65 (0.3)	1.62 (0.19)	1.96 (0.38)
35–40	1	1.63 (0.28)	1.68 (0.24)	1.77 (0.23)	2.11 (0.55)
41–45	1	1.79 (0.40)	1.95 (0.56)	2.08 (0.56)	2.15 (0.54)
46–50	1	1.63 (0.18)	1.78 (0.34)	1.90 (0.29)	2.14 (0.44)
35–40	2	1.71 (0.29)	1.78 (0.40)	1.97 (0.36)	2.29 (0.57)
41–45	2	1.80 (0.39)	1.89 (0.46)	2.08 (0.58)	2.20 (0.58)
46–50	2	1.71 (0.16)	1.83 (0.31)	1.96 (0.35)	2.30 (0.43)
35–40	3	1.81 (0.29)	1.98 (0.47)	2.23 (0.45)	2.71 (0.94)
41–45	3	1.86 (0.41)	2.09 (0.49)	2.08 (0.44)	2.34 (0.49)
46–50	3	1.87 (0.31)	2.05 (0.51)	2.16 (0.42)	2.49 (0.63)

sensitivity using the CSV-1000, which is a reliable source of clinical contrast sensitivity assessment[17] at a distance of 10 ft. CSV-1000 utilizes measurement of contrast sensitivity at 3, 6, 12 and 18 cpd of spatial frequency. However, for the current study, only 12 cpd to minimize the testing duration. In addition, 12 cpd served as a mid-spatial frequency that could tolerate more defocus than the higher spatial frequencies. Subjects viewed the grating and verbalized it as lines or patch. If the answer was right, the response duration was recorded. Otherwise, the next grating was identified and the process repeated. Only the response duration for the correctly identified grating was recorded.

Repeatability

7 subjects from the study population were initially recruited for a repeatability study. They underwent repeatability tests for response time using similar protocol as above with each of 0 and 3D defocus (low and high defocus magnitudes) at distance and near for high contrast visual acuity.

Data analysis

Data were normally distributed. This was tested using the Shapiro–WIlk test and the significance values were >0.05. The results were initially graphed and plotted as a function of response times versus defocus levels. ANOVA was performed to study the effect of defocus on response time for various tasks like logMAR visual acuity at distance, near as well as contrast sensitivity at 12 cpd. Paired t-tests were also done to assess for repeatability of the response time measurements.

Results

Repeatability

Paired t-tests were done for each condition and there was no significant difference in response times for 0D [$t(6) = -0.52$, $p = 0.617$] and 3D [$t(6) = -0.65$, $p = 0.534$] for high contrast distance visual acuity. Similarly, there was no significant difference in response times for 0D [$t(6) = 0.31$, $p = 0.764$] and 3D [$t(6) = 0.48$, $p = 0.643$] for high contrast near visual acuity.

Response time for distance visual acuity

Effect of defocus. Mean (SD) response time for low and high contrast distance visual acuity for different defocus levels in the three age groups is given in Table 1 (see Figs. 1 and 2). ANOVA revealed a significant difference (−0.33 s) in response time for high contrast visual acuity between 0 and 3D defocus in pre-presbyopic population only ($p = 0.002$). In addition, ANOVA revealed a significant difference (−0.40 s) in response time for low contrast visual acuity between 0 and 3D defocus in presbyopic population only ($p < 0.001$). For the pre-presbyopic, there was a significant difference in response time (−0.49) for low contrast visual acuity observed between 0 and 3D ($p = 0.002$), while it was −0.38 s between 1 and 3D of defocus ($p = 0.024$).

Effect of age. Mean (SD) response time for low and high contrast distance visual acuity for different defocus levels in the three age groups is given in Table 1. ANOVA revealed no significant difference in response time for high contrast acuity between the different age groups ($p > 0.05$ in all groups). However, ANOVA revealed a significant difference (−0.34 s) in response time for only low contrast acuity with 1D defocus

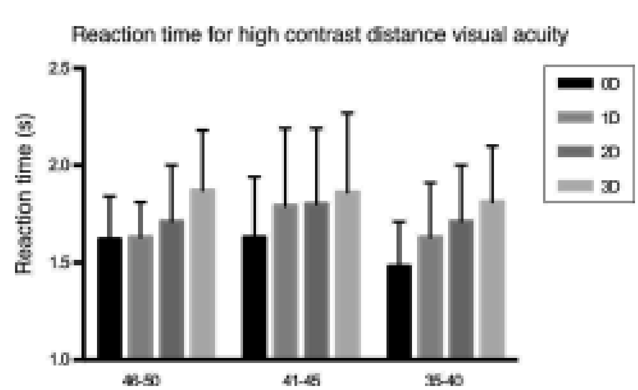

Figure 1 Plot of response time for monocular high contrast distance visual acuity in the presence of different defocus magnitudes for the three age groups.

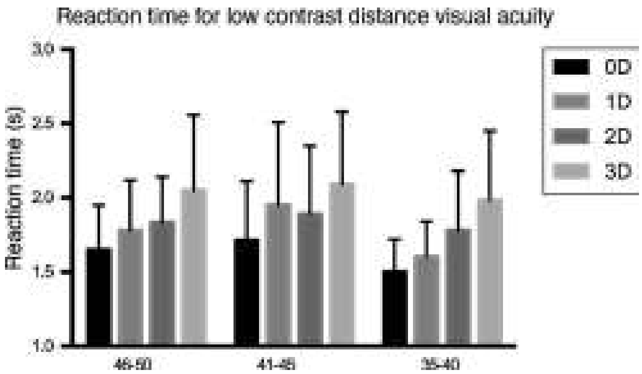

Figure 2 Plot of response time for monocular low contrast distance visual acuity in the presence of different defocus magnitudes for the three age groups.

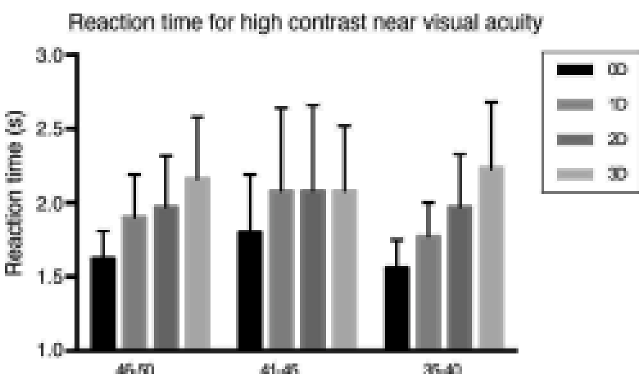

Figure 3 Plot of response time for monocular high contrast near visual acuity in the presence of different defocus magnitudes for the three age groups.

between the different pre- and mid-presbyopic age groups ($p = 0.015$).

Response time for near visual acuity

Effect of defocus. Mean (SD) response time for low and high contrast near visual acuity for different defocus levels in the three age groups is given in Table 1 (see Figs. 3 and 4). ANOVA revealed a significant difference in response time of −0.34 s for high contrast visual acuity between 0 and 2D

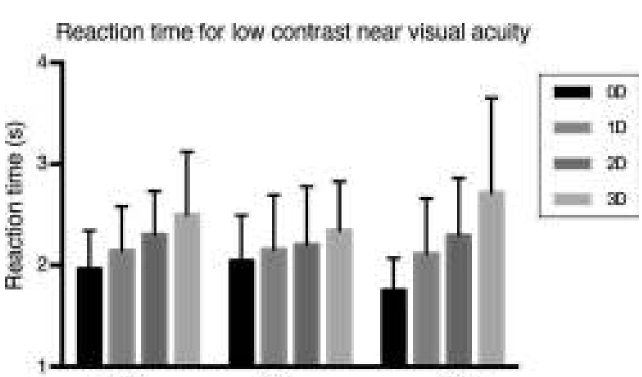

Figure 4 Plot of response time for monocular low contrast near visual acuity in the presence of different defocus magnitudes for the three age groups.

Table 2 Summary of mean (SD) response time for contrast threshold at 12 cpd in the presence of different defocus levels.

Age (years)	Defocus (D)	Contrast threshold
35–40	0	2.19 (0.53)
35–40	1	2.47 (0.71)
35–40	2	2.85 (1.02)
35–40	3	2.97 (0.74)
41–45	0	2.11 (0.50)
41–45	1	2.35 (0.45)
41–45	2	2.64 (0.50)
41–45	3	3.33 (1.14)
46–50	0	2.28 (0.60)
46–50	1	2.55 (0.59)
46–50	2	3.72 (0.75)
46–50	3	5.72 (1.09)

($p = 0.004$), while it was −0.53 s between 0 and 3D defocus in presbyopic population ($p < 0.001$). For the pre-presbyopic, there was a significant difference in response time of −0.40 s for high contrast visual acuity observed between 0 and 2D ($p = 0.01$), while it was -0.67 s between 0 and 3D defocus ($p = 0.001$). Furthermore, the difference was −0.46 s between 1 and 3D defocus ($p = 0.036$). For pre-presbyopic low contrast near acuity, the difference in response time was −0.53 s ($p = 0.001$) between 0 and 3D. In presbyopic group, the difference in response time was −0.54 s between 0 and 2D ($p = 0.001$), while the difference significantly increased to −0.61 s for 1 and 3D defocus ($p = 0.01$). Furthermore, the difference significantly increased to −1 s between 0 and 3D defocus ($p = 0.002$).

Effect of age. Mean (SD) response time for low and high contrast near visual acuity for different defocus levels in the three age groups is given in Table 1. ANOVA revealed significant difference in response time (−0.31 s) for high contrast acuity for 1D defocus between pre- and early-presbyopic groups ($p = 0.036$). In contrast, ANOVA revealed no significant difference in response time for low contrast acuity between the different presbyopic groups ($p > 0.05$ for all groups).

Response time for contrast sensitivity

Effect of defocus. Mean response time for contrast sensitivity for each defocus level at 12 cpd is summarized in Table 2. For the pre-presbyopic, there is a significant increase in response time between 0 and 2D, 0 and 3D by −0.67 ($p < 0.001$) and −0.78 s ($p < 0.001$). In addition, for the early-presbyopic, there is a significant increase in response time between 0 and 3D, 1 and 3D, 2 and 3D by −1.21 ($p < 0.001$), −0.97 ($p = 0.001$) and −0.69 ($p = 0.016$) s. Furthermore, for the mid-presbyopic, there is a significant increase in response time between the following conditions: 1 and 2D ($p < 0.001$), 0 and 2D ($p < 0.001$), 2 and 3D ($p < 0.001$), 1 and 3D ($p < 0.001$), 0 and 3D ($p < 0.001$) by −1.16, −1.44, −2, −3.44, −3.16 s.

Effect of age. Mean (SD) response time for contrast threshold for different defocus levels in the three age groups is given in Table 2. ANOVA revealed significant difference in response time only for contrast threshold for 2D defocus between pre- and mid-presbyopic groups

(-0.86 s; $p = 0.013$), early- and mid-presbyopic groups (-1 s; $p = 0.028$). Similarly, ANOVA revealed significant difference in response time only for contrast threshold for 3D defocus between pre- and mid-presbyopic groups (-2.7 s; $p = 0.001$), early- and mid-presbyopic groups (-2.3 s; $p = 0.001$).

Discussion

There were many interesting findings in the present study. The response time increased in the presence of increasing defocus levels for distance logMAR visual acuity at high and low contrast levels. The response time increased in the presence of increasing defocus levels for near logMAR visual acuity for high and low contrast levels. The response time increased in the presence of different defocus levels for a spatial frequency of 12 cpd. The response time was significantly increased for mid-presbyopic age groups for selected defocus levels with each of the visual performance tasks.

Response time for a given magnitude of defocus is different between the different age groups. It could be hypothesized that an uncorrected presbyope would have a much more difficult time with a blurred input than a 20-year-old emmetrope who can clear the target with much lower response time. In addition, as the presbyope advances in age, a slower response time, lower contrast sensitivity, and overall slower reading speed necessitates a corrective spectacle prescription for all distances. Interestingly, Kline et al.[18] reported that older patients were able to identify texts slightly better than their younger counter parts. This could be partially accounted for by pupillary miosis, which, in turn, also produces reduced retinal illumination, while increasing image contrast and depth of field. Heron et al.[19] have summarized the changes in accommodation dynamics with age using step stimuli as reported in various studies. They studied the response times for far-to-near and near-to-far tasks in subjects between 18 and 49 years of age and observed no change in response time as a function of age. There is very little information available regarding response times for different age groups during the transition period and at various stages of presbyopia. In the present study, 1D of defocus exhibited an increase in response time between early and mid-presbyopic for low contrast optotype at distance and high contrast optotype at near. No effect was observed within other defocus levels.

Does blur adaptation play a role? Blur is a primary accommodation cue and is needed for optimal functioning of the accommodation system. Several studies[20–24] have been performed on blur adaptation and defocus detection. It has been reported that exposure to a blurred image for a short period of time altered an individual's perception, thereby making those images appear to be sharper than before. Webster et al.[25] reported that a subject's perception of blur was altered by as low as a 3-min period of prior exposure to either sharply focused or blurred images. Cufflin and Mallen[20] had reported that monocular blur adaptation of 30 min to both +1 and +3D defocus increased the response time for a task with 2D step change in accommodative demand. However, in the present study, subjects were exposed to very few seconds of blur and hence may not have influenced the response time significantly.

There are tasks that need adequate vision in different lighting conditions. Driving is one such task. A very recent study by Wood et al.[26] compared the effect of different magnitudes of blur on visual acuity and contrast sensitivity as well as driving performance in both day light and night time conditions. They reported decreased visual acuity and contrast sensitivity for increasing magnitudes of blur. In addition, blur had a significant effect on driving performance like signs recognized, hazards hit, lap time and sign recognition distance. In comparison to the present study, this study was performed on younger subjects and response time was not assessed. While driving is impacted for young subjects in the presence of blur for day time and even more in the night time, uncorrected presbyopic subjects would definitely experience profound difficulty with performing tasks like sign recognition while driving. Full correction of refractive error at distance and near in presbyopes is warranted for critical tasks. Since response time is decreased at both distance and near, it is not merely the tasks a presbyopic patient performs up close that is of concern for optometrists, but also the distance visual acuity. When an individual is corrected for distance and not for near, with prolonged adaptation, any near correction, a larger response time is expected. Therefore, it is in the clinician's best interest to fully correct a pre-presbyopic and presbyopic patient's vision at all distances, not just their reading acuity. Hence, for the increased safety of society as a whole, it is crucial that pre-presbyopic and presbyopic patients are corrected for distance as well.

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None.

Conflict of interest

The authors have no conflicts of interest to declare.

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