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1 **The impact of induced optical blur on monocular and binocular depth-related**
2 **visuomotor task performance**

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30 **Abstract**

31 **Purpose:** To determine the impact of induced optical blur on a 3D task that probes complex visuomotor
32 performance capabilities of humans.

33
34 **Methods:** 15 visually normal, cyclopleged adults (mean \pm 1SD: 23 \pm 2.6 years) guided a metal loop along
35 a wire convoluted in depth without making contact, while being video recorded for analysis. The task
36 was performed binocularly and monocularly, without blur, and with two magnitudes of induced
37 spherical and astigmatic blur of equal strengths (2.25D and 6.25D). Blur patterns were induced before
38 both eyes (isometropia) or before only one eye (anisometropia). For isometric astigmatism, blur was
39 also induced with parallel and orthogonal axes in both eyes. The buzz-wire patterns, viewing condition
40 and induced blur were all randomized across participants.

41
42 **Results:** Binocular error rate (number of loop-to-wire contacts per second) and error duration
43 (percentage of time spent making errors) increased at high blur strength ($p < 0.001$), more so for
44 astigmatism than spherical power ($p < 0.001$) and more so for isometric than anisometric viewing
45 ($p = 0.02$). Low astigmatism with orthogonal axes bilaterally produced higher error rate and error
46 duration than astigmatism with parallel axes bilaterally ($p < 0.001$). Only error duration increased with
47 high blur for monocular viewing ($p \leq 0.004$). Task speed remained invariant across test conditions.
48 Multiple repetitions did not impact task performance.

49
50 **Conclusions:** The deterioration of depth-related visuomotor task performance with optical blur
51 depends on its magnitude, radial symmetry and the similarity between the two eyes. Performance drop
52 is largely from spending more time making/correcting errors, while the overall speed remained
53 undiminished.

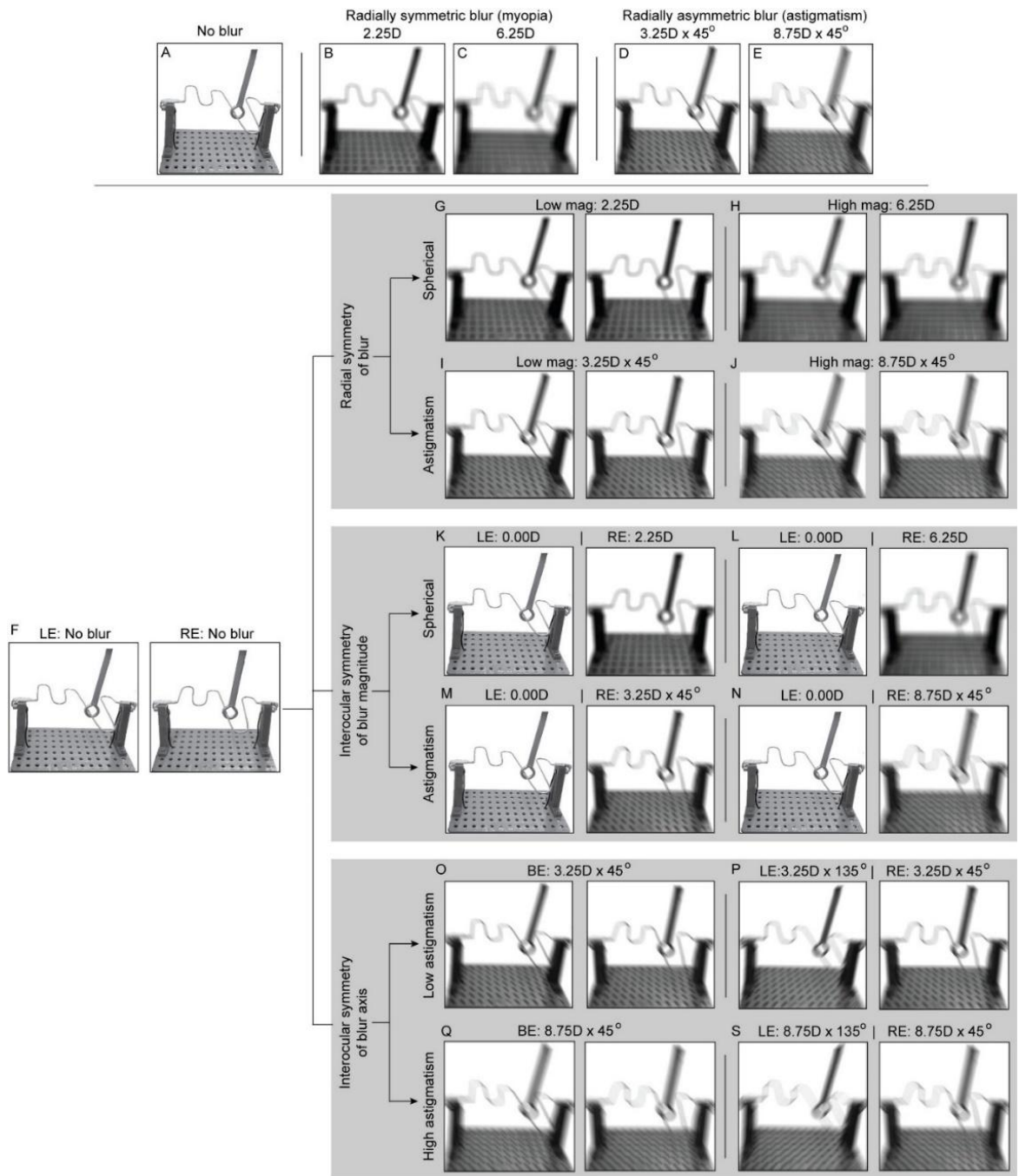
54
55 **Keywords:** Anisometropia; Astigmatism; Blur; Defocus; Stereopsis; Visuomotor

56

57 1. Introduction

58 Day-to-day activities like inserting a key into a keyhole or pouring water from a jug into a container are
59 essential visuomotor tasks that require accurate estimates of 3D depth. The hand actions associated
60 with these tasks may be guided by binocular retinal disparity plus monocular depth cues (e.g., motion
61 parallax, texture), with the weight assigned to the former cue being larger than the latter ones.^{1,2} Two
62 studies from Devi et al. support this notion using a visuomotor task that requires participants to move
63 a loop around a wire convoluted in depth without contact.^{3,4} Error rates in this task increase with the
64 loss of binocularity,³ and the associated binocular advantages (i.e., the extent to which binocular error
65 rates are lower than monocular values) decline when binocularity is compromised due to blurred vision
66 from distorted optics.^{3,4} Task speed also decreases with absent/degraded binocularity, albeit with a
67 smaller effect size than that of error rates.^{3,4} Systematically investigating the impact of blurred vision
68 on depth-related task performance is the primary goal of the present study.

69
70 Retinal image blur may impact depth-related visuomotor task performance for two reasons. First,
71 optical blur limits visual resolution by degrading contrast and inducing phase shifts in the retinal image.⁵⁻
72 ⁷ Both factors impair the ability to resolve the critical details required to perform the task (e.g.,
73 estimating the diastereoptic gap between the loop and wire in the buzz-wire task) (Figure 1). Second,
74 dissimilar blur in the two eyes impacts binocular processing by impairing correspondence matching in
75 the monocular retinal images^{8,9}, reducing the overall quality of the disparity signal⁸ and suppressing the
76 worse eye¹⁰⁻¹³. Finally, the gains of vergence-related eye movements and ocular accommodation also
77 decrease with blur, thus impairing the experience of clear and single binocular vision.^{14,15} All these
78 factors may ultimately limit the stereoscopic depth and diastereopsis calculations required by
79 visuomotor tasks (Figure 1). In the context of the Devi et al. (2025) study described above⁴, the
80 exaggerated wavefront aberrations arising from distorted optics of the eye translate into significant,
81 radially asymmetric retinal blur profiles.^{16,17} The blur profiles may also be dissimilar in the two eyes due
82 to asymmetric disease severity.^{16,17} All of these factors could have influenced the buzz-wire task
83 performance in that study.⁴ That there may be complex interactions between these blur dimensions to
84 determine visuomotor task performance is also suggested by differences in the results obtained
85 between eyes with distorted optics (keratoconus) and with regular refractive errors (uncorrected
86 myopia) in their study.⁴ The myopic cohort, characterized primarily by isometric, spherical blur
87 profiles, continued to show a binocular advantage in error rates while the keratoconic cohort,
88 characterized by complex blur profiles as described above, lost the binocular advantage.⁴



89
 90 **Figure 1:** Point-of-view simulations of the buzz-wire apparatus with clear vision (panel A) and with different
 91 patterns of monocular optical blur (panels B – E). Panel F – S shows simulated cross-fusable stereo image pairs of
 92 the different binocular viewing conditions in this study. All optical simulations were generated for 555 nm light
 93 and 5 mm pupil diameter, using standard Fourier optics techniques.¹⁸ The simulations were created by convolving
 94 the point-of-view images of buzz-wire with the point spread function obtained by inducing a specific blur along
 95 with the population-averaged higher-order Zernike wavefront aberrations reported by Cheng et al. (2004).¹⁹
 96
 97 A systematic study is required to tease out the individual and combined contributions of these blur
 98 factors on the buzz-wire task performance. *Few studies in the literature have investigated how vision*
 99 *loss from induced optical*^{20,21} *and non-optical (Bangerter filter)*²² *blur affects depth-related visuomotor*

100 *tasks like bead threading, water pouring, peg placement and sports-related interceptive actions. In*
101 *general, these studies show worsening of task performance with increasing magnitudes of blur.* Some
102 tasks like bead threading appear to be more vulnerable to optical blur compared to others like the water
103 pouring task.²¹ While, in principle, these results demonstrate the negative impact of induced blur on
104 visuomotor tasks, the relative impacts of different blur dimensions described above on such tasks
105 remains unknown. This knowledge gap was addressed in the present study by systematically
106 investigated the impact of two different magnitudes of spherical and astigmatic blur presented
107 isometropically or anisometropically on the monocular and binocular buzz-wire task performance
108 (Figure 1). The following hypotheses were tested here.

- 109 1. Monocular and binocular buzz-wire task performances will worsen with induced blur, relative to the
110 no blur condition (Figure 1F vs. B – E and Figure 1F vs. G – N). This will be so for the aforesaid reasons
111 of loss in visual resolution and binocularity.
- 112 2. Astigmatism will produce greater loss of task performance than comparable strengths of spherical
113 blur (Figures 1B and C vs. D and E, respectively). This will be so because meridional blur in astigmatism
114 may cause greater difficulty in diastereoptic judgments relative to the uniform image-quality loss
115 with spherical blur (Figures 1B and C vs. D and E, respectively). Astigmatism also tends to produce a
116 larger subjective blurring effect than spherical blur.^{23,24}
- 117 3. Anisometropia will produce greater loss of binocular task performance than comparable magnitudes
118 of isometropia (Figure 1G and H vs. K and L, respectively, and Figures 1I and J vs. M and N,
119 respectively). This will be so for the aforesaid reasons of binocularity loss with unequal magnitudes
120 of blur in the two eyes.⁸⁻¹³
- 121 4. Astigmatism with orthogonal axes in the two eyes will result in greater loss of task performance than
122 those with parallel axes in the two eyes (Figure 1O and Q vs. P and S). This will be so for the reason
123 of binocular correspondence matching.
- 124 5. The binocular advantage of task performance will deteriorate in the presence of all forms of blur
125 profiles owing to the underlying loss of binocularity, relative to the no blur condition.

126

127 **2. Methods**

128 *2.1. Participants*

129 The study adhered to the tenets of the Declaration of Helsinki, and it was approved by the Institutional
130 Review Board of L V Prasad Eye Institute (LVPEI), Hyderabad, India. The experiment was initiated after
131 all participants signed the written consent form. Fifteen participants (Mean \pm 1SD age: 23 \pm 2.6 years),

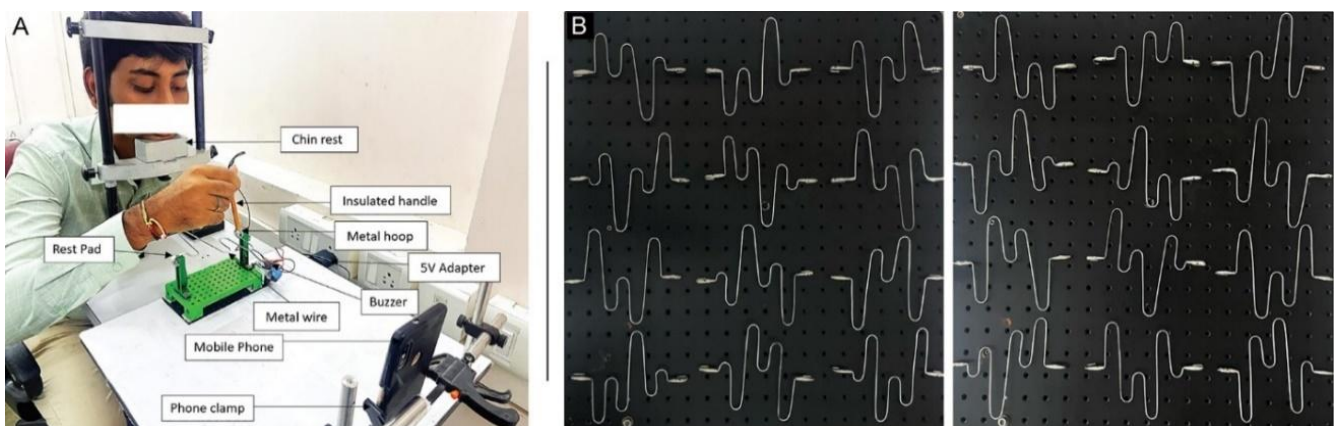
132 based on convenient sampling, were recruited for the study whose uncorrected, monocular distance
133 visual acuity was better than or equal to 20/25 in both eyes, spherical equivalent refractive error was \leq
134 $\pm 0.50D$ in both eyes, stereoacuity better than or equal to 40 arc sec and they were free of any ocular or
135 binocular vision anomalies.

136

137 *2.2. The apparatus, task and outcome measures*

138 The buzz-wire task involves passing a metallic loop around the wire pattern convoluted in depth,
139 without contact (Figure 2A). Physical contact between the loop and the wire results in an auditory
140 “buzz,” signalling an error in the task. A total of 24 unique buzz-wire patterns with five to six depth
141 modulations of 6.5 cm, 4.0 cm and 1.0 cm from the base position across the entire wire length (40.8
142 cm) were created to avoid practice effects (Figure 2B). This ensured that a given pattern was used no
143 more than twice across the entire experiment. The participant’s head was stabilized using a chin and
144 forehead rest at the beginning of the experiment, ensuring that the distance between the participants
145 and the buzz-wire setup was approximately 33 cm. Stabilizing the head also ensured that the pattern of
146 astigmatic blur experienced did not vary during the task. *The task was performed 45 – 60 mins after*
147 *instillation of 1% Cyclopentolate HCl eye drops to ensure that the induced blur profiles did not vary with*
148 *the participant’s accommodative behavior.^{26,27} The effect of cycloplegia was confirmed by near acuity*
149 *worsening to >N8 on the standard near vision chart at 40 cm viewing distance. Additional eye drops*
150 *were used, if necessary, to ensure that this criterion was met throughout the experiment. A near-*
151 *correction of +3D was placed before the participant’s eyes to account for the 33 cm viewing distance at*
152 *which the buzz-wire task was performed.*

153



154 **Figure 2:** Panel A) *The experimental set-up with the key elements highlighted. Panel B) The profiles of the 24*
155 *different buzz-wire patterns used in the experiment.*

157

158 Task instructions and the process of data cleaning and analysis is described in Devi et al. (2024, 2025).^{3,4}
159 Task performance was quantified using three outcome variables. *Error rate* was calculated as the
160 number of error buzzes over the total task duration (in errors/second). *Error duration* was calculated as
161 the total time spent in error divided by the total task duration (in percentage). *Speed* was calculated as
162 the length of the wire divided by the error-free time (in cm/second).

163
164 **2.3. The induced blur conditions**

165 The blur profiles included the two magnitudes of radially symmetric (spherical blur; Figures 1B and C)
166 or asymmetric (astigmatic blur; Figures 1D and E) blur and with the blur being equal in the two eyes
167 (isometropia; Figures 1G – J) or unequal in the two eyes (anisometropia; Figures 1K – N). Two variants
168 of isometric astigmatic blur were also tested — a profile with similar magnitude and axes of
169 astigmatism in the two eyes (45°) and a profile with similar magnitude but orthogonal axes of
170 astigmatism in the two eyes (45° in the right eye and 135° in the left eye) (Figures 1O – S). The impact
171 of blur magnitude and radial symmetry on the buzz-wire task performance was investigated under
172 binocular and monocular conditions. The impact of interocular symmetry was investigated only under
173 binocular conditions. Monocular testing was always performed on the right eye while the left eye was
174 occluded. For binocular viewing, the blur profiles were introduced either before both eyes (isometric
175 viewing) or only before the right eye (anisometric viewing) while the left eye viewing remained
176 unhindered. All blur profiles were induced using full-aperture trial lenses mounted on a trial frame at a
177 14 mm vertex distance. Each participant repeated the buzz-wire task thrice with each blur profile,
178 resulting in a total of 48 repetitions per participant ([monocular baseline + 2 monocular spherical blur
179 + 2 monocular astigmatic blur + binocular baseline + 2 isometric spherical blur + 2 isometric
180 astigmatic blur with parallel axes in the two eyes + 2 isometric astigmatic blur with orthogonal axes
181 in the two eyes + 2 anisometric spherical blur + 2 anisometric astigmatic blur] x 3 repetitions of
182 each condition = 48 trials). The first trial was always the binocular baseline condition while the order of
183 remaining trials was randomized within and across participants to minimize any practice effect (*see*
184 *Supplement II for control experiment investigating the impact of practice on the buzz-wire task*
185 *performance*). Data was collected across two days on each participant, averaging 2.5 hours per
186 participant per day. Short breaks were provided between trials or whenever required to reduce fatigue.

187
188 The two levels of optical blur were purposely chosen in this study to induce significant loss of visual
189 resolution and binocularity. (See Supplement I for an investigation of the relationship between different

190 blur magnitudes and buzz-wire task performance.) Like Piano and O'Connor (2013)¹³, the lower
191 magnitude of spherical blur (2.25D) used here resulted in a 8-line loss of visual acuity from baseline
192 (Mean \pm 1 SD visual acuity across 8 participants: 0.82 ± 0.16 logMAR) while the higher magnitude (6.25D)
193 resulted in a 14-line loss of visual acuity from baseline (1.42 ± 0.18 logMAR units).³ Comparable
194 strengths (2.30D and 6.19D) of astigmatic blur were induced using cylindrical lenses at 45 degree axes.
195 Note that the total blur strength of a spherocylindrical lens is

$$196 \quad B = \sqrt{\left(S + \frac{C}{2}\right)^2 + \left(-\frac{C}{2} \cos 2\beta\right)^2 + \left(-\frac{C}{2} \sin 2\beta\right)^2},$$

197 where S is the power of the spherical component, C is the power of the (positive) cylindrical
198 component, and β is the cylindrical axis.²⁸The cylindrical powers of our low-powered and high-powered
199 lenses were 3.25 D and 8.75 D, respectively.³⁰ Use of these lenses resulted in 7-line and 12-line acuity
200 losses, relative to baseline, in the same 8 participants (logMAR values were of 0.76 ± 0.15 and $1.25 \pm$
201 0.15 , respectively).

202
203 In addition to the buzz-wire task, stereo perception thresholds were also measured under cycloplegia
204 (but corrected for the test viewing distance), at a 50-cm viewing distance, using the technique described
205 by Devi et al. (2025).⁴⁴ Stereo thresholds worsened to ≥ 500 arcsec across all induced blur conditions.
206 Since the stereo thresholds were found to have limited correlation with the buzz-wire task performance
207 in the Devi et al. (2025)⁴ study, no further analyses of these thresholds are performed here. Instead,

³ All visual acuities were measured under photopic conditions using a computerized logMAR optotype presentation system (COMPlog Vision Measurement, London, UK).²⁵ Herein, five Sloan optotypes were randomly displayed on an LCD screen and their angular subtense decreased using a staircase algorithm until 3 out of 5 optotypes were incorrectly identified. LogMAR acuity was recorded as the number of optotypes correctly identified at termination, with 0.02 logMAR units allotted per optotypes.

³⁰ These cylindrical powers were selected as the closest available strengths matching the two spherical powers of 2.25 D and 6.25 D according to the equivalence formula described above by Thibos et al. (1997).²⁸ The specific values of matched blur strengths were 2.30 D and 6.19 D at axis 45°.

⁴ Random-dot stimuli were presented on a LCD monitor and controlled using the Psychtoolbox-3 interface of MATLAB (R2024a; The MathWorks, Natick, USA). These dichoptic stimuli were fused using a handheld stereo viewer with built-in periscopic mirrors to adjust for the participant's horizontal phoria and interpupillary distance (Screen-Vu Stereoscope, Portland, OR, USA). The cyclopean image was a vertically-oriented rectangular bar tilted either to the left or to the right in uncrossed horizontal retinal disparity. Participants indicated the direction of the bar tilt while the retinal disparity varied in a two-down and one-up adaptive staircase with each presentation for 11 reversals. While all participants had clinical stereo thresholds better than 40 arc sec (measured using Wirt circles), the average (± 1 SEM) psychophysical stereo threshold (measured with random-dot stimuli) for the baseline condition was 102 ± 19 arc sec. This difference may be attributed to the nature of the stereo stimuli as well as cycloplegia in the laboratory.²⁹

208 these data simply serve as evidence for deteriorated sensory binocularity across all the induced blur
 209 conditions in the present study.

210

211 *2.4. Statistical analyses*

212 Matlab® and SPSS® (Version 27, IBM, SPSS Inc, Armonk, USA) were used for data analyses. The Shapiro-
 213 Wilk test revealed no significant departure from normality in the three outcome variables and hence
 214 the data trends were described using parametric statistics. Several statistical analyses were performed
 215 to gain a comprehensive understanding of the impact of different combinations blur and viewing
 216 conditions on the outcome variables of the buzz-wire task. These details are shown in Table 1,
 217 categorized by the underlying study hypotheses. Hypothesis testing also involved an analysis of the
 218 binocular advantage in task performance for all three outcome measures (Table 1). *The binocular*
 219 *advantages in error rate and error duration were calculated as ratios of monocular performance to*
 220 *binocular performance. The binocular advantage in speed was calculated as the ratio of binocular speed*
 221 *to monocular speed. These calculations ensured that a ratio greater than unity indicated superior*
 222 *performance under binocular than monocular viewing. For the isometric blur condition, the*
 223 *monocular performance with the corresponding value of blur was used to compute the binocular*
 224 *advantage. For the anisometric blur condition, the monocular performance without any induced blur*
 225 *was used to compute the binocular advantage.* This was done under the assumption that the eye with

226

227 **Table 1:** Description of the different statistical analyses performed to test the study hypotheses.

	Statistics	Independent factors	Dependent variables	Text reference
Hypotheses 1 and 5: Impact of induced blur on task performance vs. baseline				
Mono viewing	1-factor RM- MANOVA	Baseline & all monocular induced blur conditions	Error rate, Error duration & Speed	Table 2, Section 2
Bino viewing		Baseline & all binocular induced blur conditions		Table 2, Section 3
Bino advantage				Table 2, Section 4
Hypotheses 2 and 3: Impact of radial and interocular symmetry of blur on task performance				
Mono viewing	2-factor RM- MANOVA	Blur magnitude & Radial symmetry of blur	Error rate, Error duration & Speed	Table 3, Section 1
Bino viewing	3-factor RM- MANOVA	Blur magnitude, radial symmetry & interocular symmetry of blur		Table 3, Section 2
Bino advantage	3-factor RM- MANOVA			Table 3, Section 3
Hypothesis 4: Impact of parallel versus orthogonal astigmatic axis on task performance				
Bino viewing	2-factor RM- MANOVA	Blur magnitude & astigmatic axis orientation	Error rate, Error duration & Speed	Table 4, Section 1
Bino advantage	2-factor RM- MANOVA			Table 4, Section 2

228 *RM-MANOVA: Repeated Measures Multiple Analysis of Variance. The column "Text reference" indicates the location in the*
 229 *tables where the results of a particular statistical analysis appear in the text.*

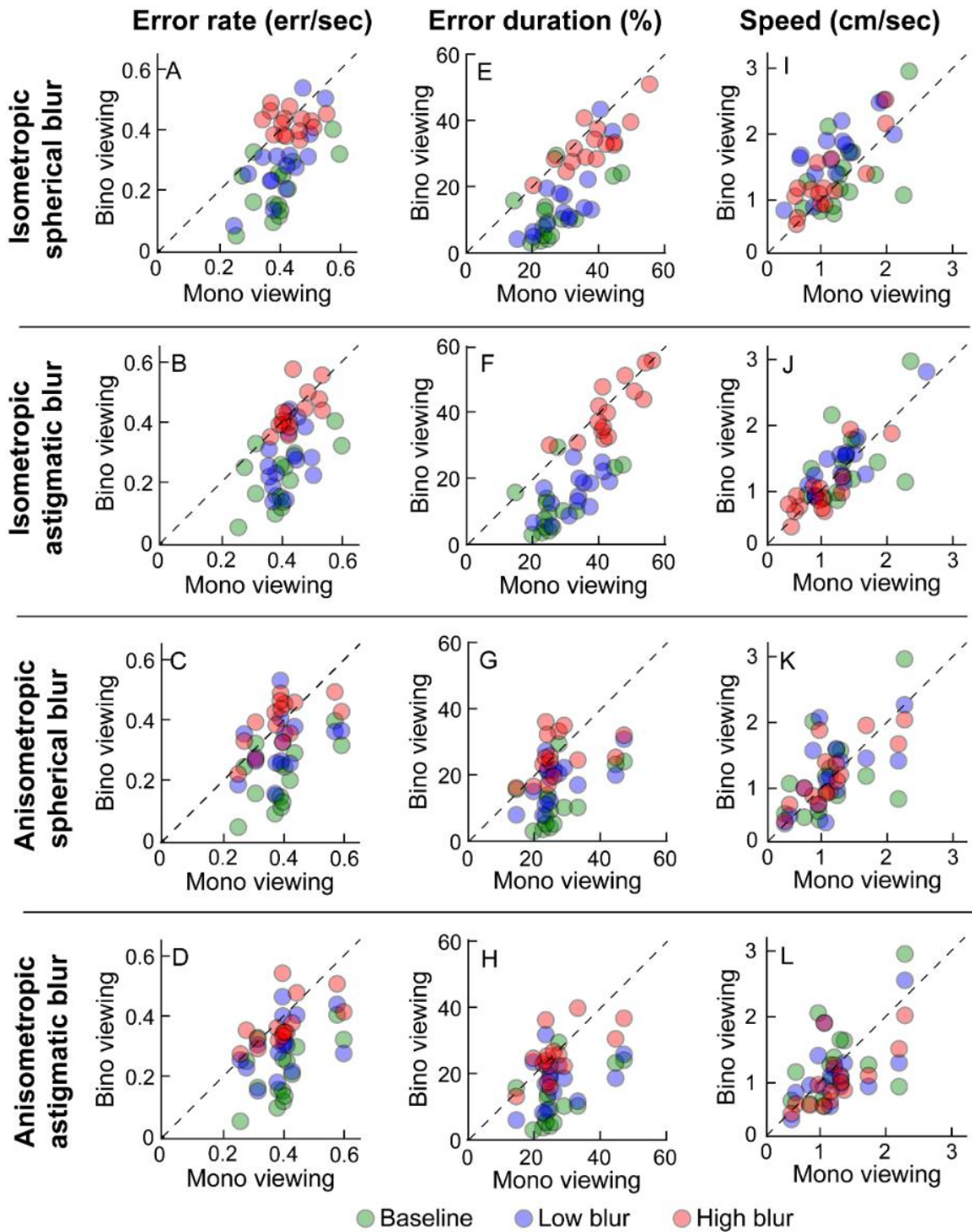
230 the clear vision is used for viewing while the fellow eye with blurred vision may be suppressed in
231 anisometropia.^{30,31} For the parallel versus orthogonal axes of astigmatism, the monocular performance
232 with corresponding value of blur at 45° and 135° axis was used to compute the binocular advantage.
233

234 3. Results

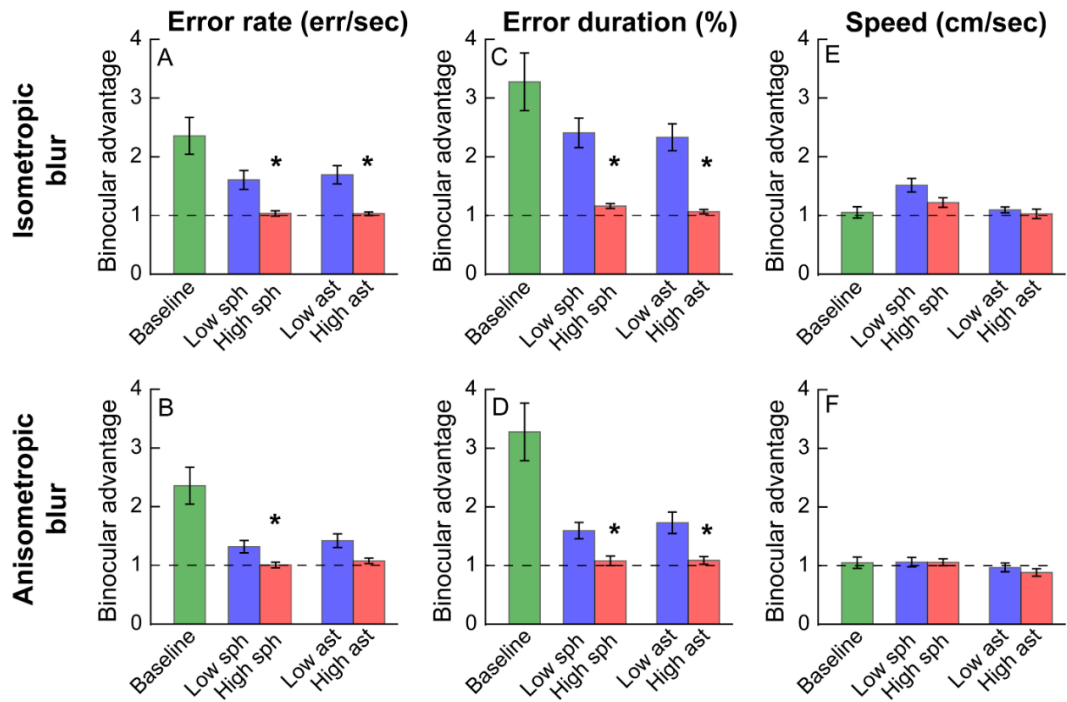
235 Figures 3 and 4 show the binocular and monocular outcome variables and the respective binocular
236 advantages for the different conditions tested in this study. The data points for the baseline (no blur)
237 and low blur conditions were below the line of equality for error rates and error durations, indicating
238 superior performance under binocular viewing (Figure 3). The distribution of data points in the baseline
239 and low blur condition overlapped, indicating no evidence for difference in task performance between
240 these two conditions (Figure 3). On the other hand, the data distribution for the high induced blur
241 condition shifted upward to the right in isometropia and simply upward in anisometropia, indicating
242 increased error rates and error durations, relative to the other conditions (Figure 3, left and middle
243 column). Accordingly, the baseline viewing showed a robust binocular advantage for the two outcome
244 variables in Figures 4A – D. This advantage was present but lower than the baseline condition for the
245 low blur conditions, irrespective of radial or interocular symmetry (Figures 4A – D). There was no
246 evidence for a binocular advantage in the high blur conditions (Figures 4A – D). Speed as an outcome
247 parameter did not indicate any specific trend, regardless of blur conditions.
248

249 3.1. Impact of induced blur on buzz-wire task performance, relative to baseline viewing

250 The 1-factor RM-MANOVA showed a significant main effect of induced blur on the monocular and
251 binocular task performance ($p < 0.001$) and on the binocular advantage of task performance ($p < 0.001$).
252 For monocular viewing, Bonferroni-corrected pairwise comparison revealed significant worsening of
253 task performance from the baseline condition only for error duration with high spherical and astigmatic
254 blur (Table 2, Section 2). For binocular viewing, the error rates and error durations were significantly
255 higher than baseline condition for high spherical and astigmatic blur under isometric and
256 anisometric viewing conditions (Table 2, Section 3). Similarly, the binocular advantage for error rate
257 and error duration was also significantly lower than the baseline condition for only the high spherical
258 and astigmatic blur under isometric and anisometric viewing conditions (Table 2, Section 4).
259



260
 261 **Figure 3:** Scatter diagrams of binocular and monocular error rate (panels A – D), error duration (panels E – H) and
 262 speed (panels I – L) under baseline no-blur condition (green circles), low blur (blue circles) and high blur (red circles)
 263 viewing conditions. The top two rows show data for isometric blur and the bottom two rows show equivalent
 264 data for anisometric blur. The same baseline data is plotted in each panel for ease of comparison. The dashed
 265 diagonal line in each panel represents equal binocular and monocular performance.



266
 267 **Figure 4:** Mean \pm 1 SEM binocular advantage in error rate (panels A and B), error duration (panels C and D), and
 268 speed (panels E and F), under baseline no-blur condition (green bars), low blur (blue bars) and high blur (red bars)
 269 viewing conditions. The dashed horizontal line in each panel indicates the level of no binocular advantage. The
 270 baseline data are the same between isometric and anisometric blur conditions. The asterisk denotes the blur
 271 conditions that were significantly different ($p < 0.05$) from baseline.
 272

273 **Table 2:** Baseline parameters of error rate, error duration and speed under binocular and monocular viewing
 274 condition (Section 1). Results of the post-hoc Bonferroni test conducted as part of the 1-factor RM-MANOVA
 275 analysis to compare the error rate, error duration and speed under baseline and the different induced blur
 276 conditions (Section 2-4).

Section 1: Baseline Parameters						
	Error rate (err/sec)		Error duration (%)		Speed (cm/sec)	
	Mean \pm SEM	p value	Mean \pm SEM	p value	Mean \pm SEM	p value
Monocular	0.39 \pm 0.02		26.97 \pm 2.22		1.37 \pm 0.11	
Binocular	0.20 \pm 0.02	<0.001	11.81 \pm 2.10	<0.001	1.38 \pm 0.14	0.47
Section 2: Monocular viewing						
	Error rate (err/sec)		Error duration (%)		Speed (cm/sec)	
	Mean diff \pm SEM	p value	Mean diff \pm SEM	p value	Mean diff \pm SEM	p value
Low sph	-0.01 \pm 0.02	>0.99	-2.89 \pm 1.99	>0.99	0.14 \pm 0.10	>0.99
High sph	-0.04 \pm 0.27	>0.99	-10.82 \pm 2.36	0.004	0.28 \pm 0.10	0.18
Low astig	-0.02 \pm 0.02	>0.99	-5.63 \pm 1.82	0.79	0.12 \pm 0.08	>0.99
High astig	-0.04 \pm 0.02	0.92	-16.03 \pm 1.62	<0.001	0.42 \pm 0.12	0.04
Section 3: Binocular viewing						
	Error rate (err/sec)		Error duration (%)		Speed (cm/sec)	
	Mean diff \pm SEM	p value	Mean diff \pm SEM	p value	Mean diff \pm SEM	p value
Low sph iso	-0.08 \pm 0.03	>0.99	-4.20 \pm 2.80	>0.99	-0.34 \pm 0.17	>0.99
High sph iso	-0.21 \pm 0.02	<0.001	-20.91 \pm 1.90	<0.001	0.10 \pm 0.16	>0.99
Low astig iso	-0.06 \pm 0.03	>0.99	-4.11 \pm 1.87	>0.99	0.04 \pm 0.10	>0.99
High astig iso	-0.22 \pm 0.03	<0.001	-29.06 \pm 2.08	<0.001	0.46 \pm 0.16	0.43
Low sph aniso	-0.11 \pm 0.03	0.03	-6.52 \pm 2.15	0.32	-0.03 \pm 0.13	>0.99
High sph aniso	-0.18 \pm 0.03	<0.001	-13.91 \pm 2.30	<0.001	-0.03 \pm 0.15	>0.99
Low astig aniso	-0.09 \pm 0.03	0.46	-5.97 \pm 2.62	>0.99	0.10 \pm 0.12	>0.99
High astig aniso	-0.16 \pm 0.03	<0.001	-13.72 \pm 2.67	0.01	0.21 \pm 0.14	>0.99

	Section 4: Binocular advantage					
	Error rate (err/sec)		Error duration (%)		Speed (cm/sec)	
	Mean diff ± SEM	p value	Mean diff ± SEM	p value	Mean diff ± SEM	p value
Low sph iso	0.75 ± 0.30	0.91	0.87 ± 0.48	>0.99	-0.46 ± 0.16	0.44
High sph iso	1.32 ± 0.31	0.02	2.12 ± 0.49	0.02	-0.17 ± 0.12	>0.99
Low astig iso	0.66 ± 0.31	1.00	0.95 ± 0.48	>0.99	-0.04 ± 0.10	>0.99
High astig iso	1.32 ± 0.32	0.03	2.21 ± 0.49	0.02	0.02 ± 0.14	>0.99
Low sph aniso	1.03 ± 0.29	0.09	1.68 ± 0.48	0.12	-0.01 ± 0.10	>0.99
High sph aniso	1.35 ± 0.32	0.03	2.19 ± 0.50	0.02	-0.01 ± 0.11	>0.99
Low astig aniso	0.93 ± 0.35	0.61	1.55 ± 0.56	0.53	0.08 ± 0.10	>0.99
High astig aniso	1.28 ± 0.32	0.05	2.19 ± 0.53	0.03	0.17 ± 0.11	>0.99

277 *Negative values of the mean difference indicate increased error rate, error duration and speed with induced blur, relative to*
278 *baseline viewing. Sections 1 and 2 of this table show the results for monocular and binocular viewing, respectively. Section 3*
279 *shows the results for binocular advantage. Comparisons that reached significance at $p \leq 0.05$ are indicated in bold.*

280 3.2. Impact of radial and bilateral symmetry of blur on buzz-wire performance

282 The 2-factor RM-MANOVA for monocular viewing revealed significant main effects of blur magnitude
283 and radial symmetry across all three outcome variables (Table 3, Section 1a). Univariate analyses
284 revealed significant effects of blur magnitude and radial symmetry only for the error duration (Table 3,
285 Section 1b) and a significant effect of blur magnitude on the speed (Table 3, Section 1b). The 3-factor
286 RM-MANOVA revealed significant main effect of all the three factors (blur magnitude, radial symmetry
287 of blur and interocular symmetry of blur) on binocular task performance (Table 3, Section 2a).
288 Significant interactions were also noted between the factors, indicating that the impact of these factors
289 on the binocular buzz-wire task performance is not independent of each other (Table 3, Section 2a).
290 The univariate analyses indicated significant main effects and interactions for the error duration
291 variable (Table 3, Section 2b). Only sporadic factors were significant for error rates and speed, as
292 highlighted in Table 3, Section 2b.

293
294 The three-factor RM-MANOVA also revealed significant main effects of all three factors on binocular
295 advantage along with a significant interaction between blur magnitude and interocular symmetry (Table
296 3, Section 3a). Univariate analyses showed a significant loss of binocular advantage in error rate only
297 with blur magnitude (Table 3, Section 3b). The binocular advantage in error duration significantly
298 deteriorated for both blur magnitude and interocular symmetry of blur, with significant interaction
299 between the two factors (Table 3, Section 3b). The binocular advantage in speed also showed a
300 significant loss with all these main factors (Table 3, Section 3b).

301
302
303

304 **Table 3: Results of 2-factor and 3-factor RM-MANOVAs performed to determine the effect of different patterns**
 305 **of induced blur on the monocular and binocular task performance, respectively.**

Section 1: 2-factor RM-MANOVA for monocular performance

1a. Multivariate tests

	F	p value	Partial η^2
Blur magnitude	13.56	<0.001	0.77
Radial symmetry	4.81	0.02	0.54
Blur magnitude x Radial symmetry	1.34	0.30	0.25

1b. Univariate tests

		Error Rate			Error Duration			Speed		
		Mean \pm SEM	p value	Partial η^2	Mean \pm SEM	p value	Partial η^2	Mean \pm SEM	p value	Partial η^2
Blur magnitude	Low	0.41 \pm 0.01	0.1	0.17	31.23 \pm 1.78	<0.001	0.74	1.24 \pm 0.11	0.001	0.53
	High	0.43 \pm 0.01			40.39 \pm 2.02			1.02 \pm 0.10		
Radial symmetry	Spherical	0.42 \pm 0.01	0.54	0.02	33.82 \pm 1.96	0.006	0.42	1.16 \pm 0.11	0.37	0.05
	Astigmatic	0.42 \pm 0.01			37.80 \pm 1.77			1.10 \pm 0.10		
Blur magnitude x Radial symmetry		-	0.93	0.0001	-	0.27	0.08	-	0.09	0.19

Section 2: 3-factor RM-MANOVA for binocular performance

2a. Multivariate tests

	F	p value	Partial η^2
Blur magnitude	75.81	<0.001	0.95
Radial symmetry	13.46	<0.001	0.77
Interocular symmetry	4.78	0.02	0.54
Blur magnitude x Radial symmetry	4.13	0.03	0.5
Radial symmetry x Interocular symmetry	5.78	0.01	0.6
Blur magnitude x Interocular symmetry	47.3	<0.001	0.92
All interactions	1.2	0.35	0.23

2b. Univariate tests

		Error Rate			Error Duration			Speed		
		Mean \pm SEM	p value	Partial η^2	Mean \pm SEM	p value	Partial η^2	Mean \pm SEM	p value	Partial η^2
Blur magnitude	Low	0.30 \pm 0.02	<0.001	0.81	17.02 \pm 1.64	<0.001	0.94	1.45 \pm 0.11	<0.001	0.62
	High	0.41 \pm 0.01			31.22 \pm 1.63			1.21 \pm 0.10		
Radial symmetry	Spherical	0.36 \pm 0.02	0.15	1.42	23.2 \pm 1.68	0.03	0.29	1.46 \pm 0.11	0.001	0.56
	Astigmatic	0.34 \pm 0.02			25.03 \pm 1.56			1.19 \pm 0.11		
Interocular symmetry	Isometropia	0.36 \pm 0.02	0.47	0.04	26.39 \pm 1.91	0.004	0.45	1.33 \pm 0.11	0.96	0.0001
	Anisometropia	0.35 \pm 0.02			21.85 \pm 1.48			1.39 \pm 0.11		
Blur magnitude x Radial symmetry		-	0.70	0.01	-	0.03	0.28	-	0.64	0.01
Blur magnitude x Interocular symmetry		-	0.01	0.37	-	<0.001	0.87	-	<0.001	0.62
Radial symmetry x Interocular symmetry		-	0.17	0.13	-	0.04	0.27	-	0.004	0.47
All interactions		-	0.43	0.04	-	0.06	0.22	-	0.36	0.05

Section 3: 3-factor RM-MANOVA for binocular advantage

3a. Multivariate tests

	F	p value	Partial η^2
Blur magnitude	12.72	<0.001	0.76
Radial symmetry	4.73	0.02	0.54
Interocular symmetry	6.75	0.006	0.63
Blur magnitude x Radial symmetry	0.35	0.79	0.08

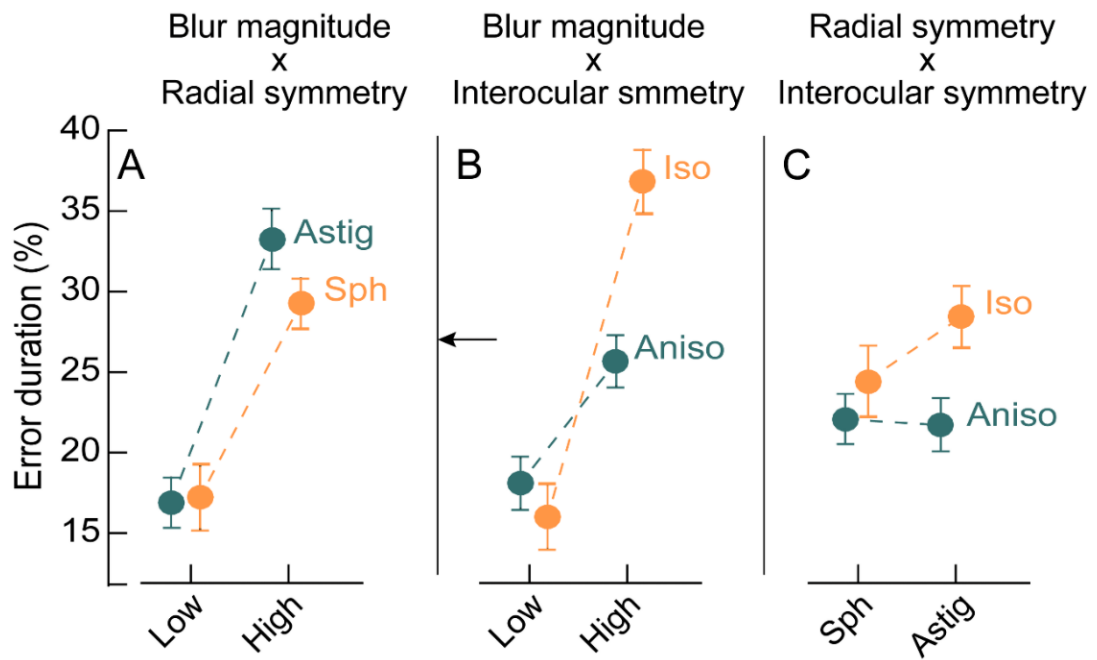
Radial symmetry x Interocular symmetry	1.14	0.37	0.22
Blur magnitude x Interocular symmetry	5.24	0.02	0.56
All interactions	0.88	0.48	0.18

3b. Univariate tests

		Error Rate			Error Duration			Speed		
		Mean ± SEM	p value	Partial η ²	Mean ± SEM	p value	Partial η ²	Mean ± SEM	p value	Partial η ²
Blur magnitude	Low High	1.51 ± 0.08 1.04 ± 0.02	<0.001	0.73	2.02 ± 0.14 1.10 ± 0.04	<0.001	0.74	1.16 ± 0.04 1.05 ± 0.04	0.03	0.28
Radial symmetry	Spherical Astigmatic	1.24 ± 0.05 1.30 ± 0.06	0.29	0.08	1.56 ± 0.08 1.55 ± 0.09	0.92	0.001	1.21 ± 0.04 0.99 ± 0.05	0.002	0.51
Interocular symmetry	Isometropia Anisometropia	1.34 ± 0.06 1.21 ± 0.07	0.15	0.14	1.74 ± 0.10 1.37 ± 0.09	0.007	0.41	1.21 ± 0.04 0.99 ± 0.06	0.02	0.33
Blur magnitude x Radial symmetry		-	0.60	0.02	-	0.69	0.01	-	0.32	0.07
Blur magnitude x Interocular symmetry		-	0.05	0.25	-	0.001	0.53	-	0.16	0.14
Radial symmetry x Interocular symmetry		-	0.68	0.01	-	0.33	0.07	-	0.08	0.20
All interactions		-	0.84	0.003	-	0.77	0.006	-	0.13	0.16

306 *Sections 1 and 2 of this table show the results for monocular and binocular viewing, respectively. Section 3 of this table show*
307 *the results for binocular advantage. Comparisons that reached statistical significance at $p \leq 0.05$ are indicated in bold.*
308

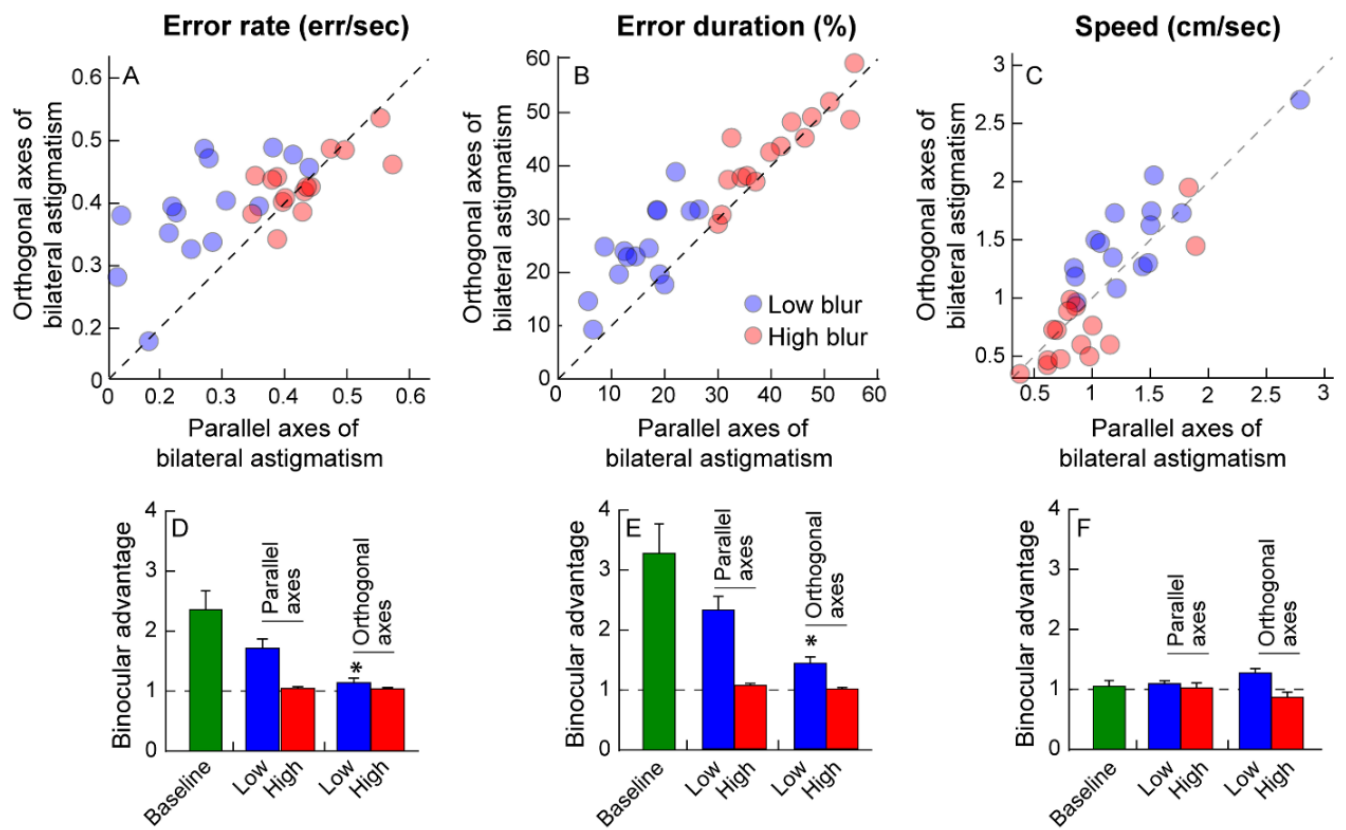
309 To better understand the nature of interactions between the different dimensions of blur, the error
310 duration variable is plotted in Figure 5 for the different interaction elements shown in Table 3, Section
311 2b. Figure 5A plots the interaction between blur magnitude and its radial symmetry across the
312 combined isometropic and anisometropic viewing conditions. The error durations were not statistically
313 different for low spherical and astigmatic blur ($t = 1.99$, $p = 0.06$) but they were significantly higher for
314 astigmatic than spherical blur at the high blur magnitude ($t = 9.77$, $p < 0.001$) (Figure 5A). Figure 5B plots
315 the interaction between blur magnitude and its interocular symmetry across the combined spherical
316 and astigmatic viewing conditions. The error durations were not statistically different for low
317 magnitudes of isometropic and anisometropic blur ($t = -1.47$, $p = 0.15$) but they were significantly higher
318 for isometropic viewing than anisometropic viewing for the high magnitude of blur ($t = 6.94$, $p < 0.001$)
319 (Figure 5B). The mean (± 1 SEM) error duration in the high anisometropic condition ($25.63 \pm 1.58\%$) also
320 matched the mean error duration observed under the monocular baseline no blur viewing condition
321 ($26.97 \pm 2.22\%$) (see horizontal arrow location in Figure 5B). The results indicate worse task
322 performance with the high magnitude of isometropic than with a comparable level of anisometropic
323 blur. Figure 5C plots the interaction between the radial and interocular symmetry of blur across the
324 combined low and high blur magnitudes. Isometropic blur resulted in overall higher error durations
325 than anisometropic blur, but this difference was greater for astigmatic than for spherical blur ($t = 9.77$,
326 $p < 0.001$) (Figure 5C).



327
 328 **Figure 5:** Impact of interactions between blur magnitude, radial symmetry and interocular symmetry of blur on
 329 the mean ± 1 -SEM error duration in the binocular buzz-wire task. Panel A shows the interaction of blur magnitude
 330 and radial symmetry of blur for the combined isometric and anisometric blur conditions. Panel B shows the
 331 interaction of blur magnitude and interocular symmetry of blur for the combined spherical and astigmatic blur
 332 conditions. The horizontal arrow indicates the mean baseline (no blur) error duration for monocular viewing.
 333 Panel C shows the interaction of radial and interocular symmetry of blur for the combined low and high
 334 magnitudes of blur. The data points in each panel are connected only to highlight the interaction between the
 335 factors.

336
 337 **3.3. Impact of the bilateral symmetry of astigmatic axis on buzz-wire performance**

338 Error rates (panel A) and error durations (panel B) were worse for the low blur condition with
 339 orthogonal axes orientation, relative to the parallel axes orientation (Figure 6). This effect was absent
 340 for the high blur condition, with both sets of data falling along the line of equality (Figures 6A and B).
 341 Speed decreased with blur magnitude for both parallel and orthogonal axes orientations (Figure 6C).
 342 The 2-factor RM-MANOVA revealed a significant main effect of blur magnitude and interocular
 343 astigmatic axis orientation and a significant interaction between the factors on the combined outcome
 344 variables (Table 4, Section 1a). Univariate tests revealed blur magnitude to have a significant effect on
 345 all three outcome variables while the axis orientation had an effect only on the error rate and error
 346 duration (Table 4, Section 1b). The binocular advantage for error rate (Figure 6D) and error duration
 347 (Figure 6E) decreased with astigmatic blur (see also Table 4, Section 2). It was completely lost when the
 348 magnitude of astigmatism was high, irrespective of its axis orientation (Figures 6D and E and Table 4,
 349 Section 2). Speed did not show any such trend in the binocular advantage (Figure 6F and Table 4, Section
 350 2).



351
 352 **Figure 6:** Outcome variables (as scatter diagrams in panels A–C) and binocular advantages (as bar graphs in
 353 panels D–F) with parallel and orthogonal axes of astigmatism in the two eyes under low and high blur viewing
 354 conditions. The asterisk symbols in panels D and E indicate significant differences between parallel and orthogonal
 355 axes.

356
 357 **Table 4:** Results of 2-factor RM-MANOVA performed to determine the impact of astigmatic axis orientation on
 358 binocular buzz-wire task performance.

Section 1: 2-factor RM-MANOVA for binocular performance

1a. Multivariate tests

	F	p value	Partial η^2
Blur magnitude	14.13	<0.001	0.95
Bilateral axes	87.85	<0.001	0.77
Blur magnitude x Bilateral axes	11.55	0.001	0.74

1b. Univariate tests

		Error Rate			Error Duration			Speed		
		Mean \pm SEM	p value	Partial η^2	Mean \pm SEM	p value	Partial η^2	Mean \pm SEM	p value	Partial η^2
Blur magnitude	Low	0.33 \pm 0.02	<0.001	0.61	20.15 \pm 1.68	<0.001	0.95	1.44 \pm 0.11	<0.001	0.75
	High	0.43 \pm 0.01			41.92 \pm 2.10			0.86 \pm 0.10		
Axis orientation	Parallel	0.35 \pm 0.02	<0.001	0.69	28.40 \pm 1.83	<0.001	0.68	1.14 \pm 0.10	0.62	0.01
	Orthogonal	0.41 \pm 0.01			33.67 \pm 1.87			1.16 \pm 0.10		
Blur magnitude x Axis orientation	–	–	<0.001	0.61	–	0.001	0.54	–	0.005	0.43

Section 2: 2-factor RM-MANOVA for binocular advantage

2a. Multivariate tests

	F	p value	Partial η^2
Blur magnitude	11.43	0.001	0.74
Bilateral axes	7.45	0.004	0.65

Blur magnitude x Bilateral axes	10.94	0.001	0.73
---------------------------------	-------	--------------	------

2b. Univariate tests

		Error Rate			Error Duration			Speed		
		Mean ± SEM	p value	Partial η ²	Mean ± SEM	p value	Partial η ²	Mean ± SEM	p value	Partial η ²
Blur magnitude	Low	1.41 ± 0.10	0.001	0.55	1.88 ± 0.15	<0.001	0.68	1.18 ± 0.95	0.02	0.31
	High	1.03 ± 0.02			1.03 ± 0.03			0.947 ± 0.08		
Axis orientation	Parallel	1.36 ± 0.09	0.002	0.52	1.70 ± 0.12	<0.001	0.60	1.06 ± 0.05	0.82	0.004
	Orthogonal	1.07 ± 0.04			1.22 ± 0.06			1.07 ± 0.05		
Blur magnitude x Axis orientation	-	-	0.001	0.53	-	0.001	0.56	-	0.003	0.49

359

360 **4. Discussion**

361 *4.1. Summary of results*

362 *Depth-related visuomotor task performance deteriorates in the presence of induced optical blur under*
363 *binocular and monocular viewing conditions.* The specific study results may be summarized as follows:

- 364 1) Error rates and error duration increased with induced optical blur under monocular and binocular
365 viewing conditions, vis-à-vis, no blur viewing. While this deterioration progressively increased with
366 the magnitude of optical blur (see Supplement I), it reached statistical significance only with the
367 high magnitudes of blur.
- 368 2) A high magnitude of astigmatic blur resulted in higher error rates and error durations in the buzz-
369 wire task, relative to a comparable magnitude of radially symmetric spherical blur. Low astigmatic
370 blur with orthogonal axes in the two eyes produced higher error rates and error durations than
371 comparable blur patterns with parallel axes in the two eyes. This effect is absent with high
372 magnitudes of astigmatic blur.
- 373 3) While similarly low levels of isometric and anisometric blur had similar effects on visuomotor
374 performance, similarly high levels of isometric and anisometric blur did not. In particular, error
375 durations were much greater with high levels of isometric blur than with anisometric blur.
- 376 4) The worsening of the error rate and error duration with optical blur was greater for binocular than
377 monocular viewing conditions. This reflected as an attenuation of the binocular advantage of task
378 performance with low blur viewing and a complete loss of binocular advantage with high blur
379 viewing, all relative to baseline no blur viewing.
- 380 5) The deterioration in buzz-wire task performance manifested differently across outcome variables in
381 this study. The error duration (i.e., the percentage of total task time spent in error) was most
382 sensitive to the presence of optical blur while the speed was least sensitive.

383

384 Overall, these results support all but the third study hypothesis (*see Section 4.2 for details*). The results
385 also agree with the previous literature that demonstrated losses in visuomotor task performance and
386 prehensile movements with degraded binocularity arising from induced anisometropia^{13,20}, induced
387 visibility loss through Bangerter foils²², and in pathologies like keratoconus⁴ or amblyopia.^{33,34} The
388 present study also extends these findings to other dimensions of blur (radial and interocular symmetry)
389 that are hitherto absent in the literature to the best of the authors' knowledge.

390

391 *4.2. Buzz-wire task performance with isometropia and anisometropia*

392 Interocular differences in blur magnitude (and/or axes) result in different retinal image qualities and/or
393 aniseikonia, either of which may severely disrupt binocularity.^{10,35} This disruption of binocularity may
394 have been responsible for our participants' relatively poor performances in the buzz-wire task, when
395 compared with what they were able to achieve with similarly blur magnitudes (and/or identical axes)
396 in the two eyes. (See Figures 1O and 1P to qualitatively experience this effect). Low magnitudes of
397 spherical and astigmatic anisometropia also led to higher error duration relative to isometropia, even
398 while this result did not reach statistical significance. Counterintuitively, isometropia led to greater task
399 deterioration than anisometropia for high magnitudes of blur. This finding may be explained by the
400 suppression of the blurred input in anisometropia, thus biasing the buzz-wire task towards the
401 monocular performance of the eye with clear vision. This is suggested from the error duration with high
402 anisometropia becoming similar to the baseline monocular viewing in Figure 5B of this study. This effect
403 may also be observed qualitatively in Figure 1, wherein free-fusion of the simulated anisometric
404 image pair results in a clear cyclopean percept (Figures 1L and N) while free-fusion of simulated
405 isometric image pair results in a blurred cyclopean percept (Figures H and J). Indeed, this magnitude
406 of anisometropia was found to induce suppression in the Piano and O'Connor study¹³ from which the
407 blur values were chosen for the present study. Thus, even while the disparity signals may have become
408 effectively useless, the monocular depth cues from the eye with clear vision could be reliably used to
409 perform the buzz-wire task. In contrast, the visual system experiences a double whammy with high
410 magnitude of isometropia – there is a loss of binocularity that negatively impacts stereopsis calculation
411 and there is also a loss in spatial resolution that may preclude effective usage of the monocular depth
412 cues. This monocular advantage may not be available in anisometropes with different magnitudes of
413 blur in the two eyes (e.g., high blur in one eye and low blur in the fellow eye). This condition was,
414 however, not tested here given the already exhaustive list being investigated.

415

416 *4.3. Speed-accuracy trade-off*

417 Speed-accuracy trade-offs in motor tasks are usually assessed with a change in payoff matrix.³² If
418 behaviour changes with the payoff matrix, it may be due to a change in strategy, although one cannot
419 rule out additional changes in perception. In the present study, changes in error rate (inverse of task
420 accuracy) and speed with task difficulty may not necessarily reflect changes in response strategy, as the
421 perception of the task itself changed with the different blurring lenses used in the study. In this context,
422 a harder task can be expected to decrease response speed and/or increase the error rate. Only in 2 of
423 our 15 participants, speed was positively correlated with error rate across the various blur conditions
424 ($p < 0.05$). Consciously or unconsciously, these participants may have sacrificed accuracy to maintain
425 speed across various blur conditions. Others did not show this correlation, indicating that sacrifices in
426 speed or accuracy to optimize the complementary parameter is not a commonly observed phenomenon
427 in the buzz-wire task.

428

429 *4.4. Clinical and practical implications of this study*

430 The present study was motivated by the previous observation of poorer buzz-wire task performance in
431 individuals with keratoconus, relative to those with uncorrected myopia.⁴ The present results indicate
432 that the combination of radial and interocular asymmetry of blur in keratoconus may have resulted in
433 the greater loss of buzz-wire performance in this cohort, compared to their myopic counterparts. This
434 observation, however, must be treated with caution, for the keratoconic cohort in the previous study
435 were all corrected for their sphero-cylindrical refractive error. The retinal image quality of these
436 participants may have thus be dominated by the radially asymmetric higher-order aberration terms
437 (e.g., coma and trefoil^{16,17}) and by any residual defocus and astigmatism that remained uncorrected.
438 The present study did not induce blur from higher-order aberrations and thus its direct impact on the
439 buzz-wire task performance remains unknown. Introduction of such patterns of blur before the eye is
440 non-trivial, for it requires the use of advanced phase plates^{36,37} or adaptive optics devices,³⁸ over a
441 defined pupil size. Integration of such technology with visuomotor tasks is futuristic, at best.

442

443 The study has some practical implications for activities of daily living with blurred vision. Humans may
444 perform visuomotor tasks with compromised vision that arises from their eye ailment (e.g., uncorrected
445 refractive errors, cataract, retinal pathology) or due to poor compliance in wearing their refractive
446 correction. Whether or not visuomotor performance is impaired depends both on the task
447 requirements and on the extent of vision loss. For instance, tasks that require only a gross judgment of

448 depth may remain unimpaired in the presence of mild to moderate optical blur, while those that require
449 finer depth judgments may be negatively impacted for comparable levels of blur. This is in line with the
450 observations of Mann et al.²¹ wherein the degree of blur affected the interceptive tasks between a bat
451 and a ball traveling at a certain speed in their study. Piano and O'Connor¹³ also observed that a water-
452 pouring task requiring gross binocularity remained unimpaired with induced spherical anisometric
453 blur, while a bead-threading task (especially with smaller beads) requiring finer levels of binocularity
454 was significantly impaired by comparable levels of blur. Clinicians are thus urged to consider the task
455 requirements of their patients while planning the blur correction strategy (e.g., contact lens versus
456 spectacle correction for certain sports activity) or counselling patients about their engagements in
457 certain activities of daily living.³⁹ As a corollary to this point, the study also recommends inclusion of a
458 battery of functional vision tests that mimic routine activities of daily living with varying spatial and
459 depth vision requirements. This may reduce the discordance often observed between the patient's
460 clinical assessment that are largely based on measures of "sensory perception" (e.g., visual acuity,
461 contrast sensitivity, stereoacuity) and their ability to perform complex daily vision tasks. The latter tasks
462 tend to challenge patients more than what may be expected from clinical vision testing.^{40,41}

463

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468

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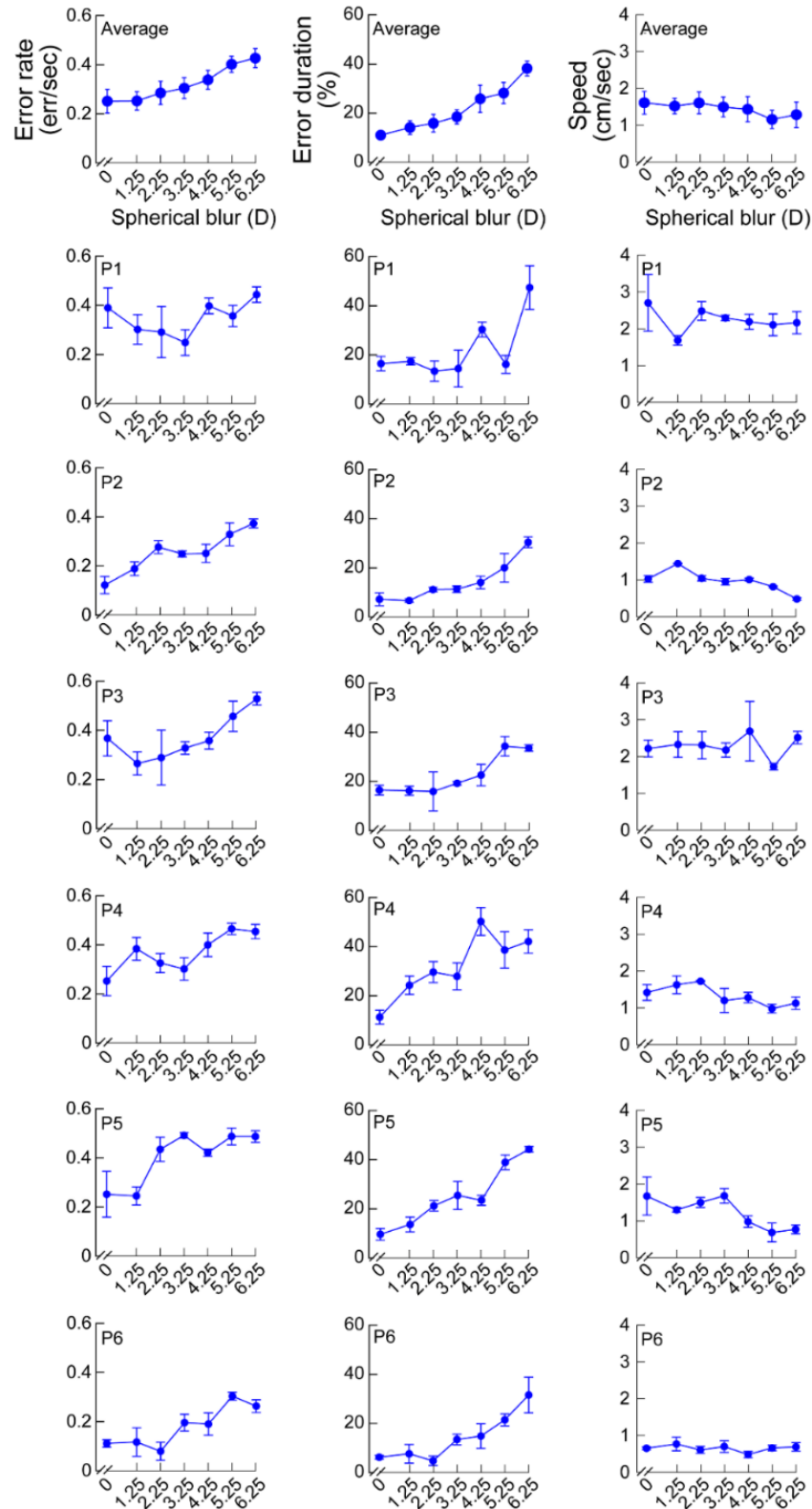
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566 **Supplementary information**

567 **Supplement 1**

568 Although high blur magnitudes ($6.25D \times 45^\circ$ and $8.75D \times 45^\circ$) produced performance deteriorations
569 in the main experiment, low blur magnitudes ($2.25D \times 45^\circ$ and $3.25D \times 45^\circ$) did not show any
570 evidence for being different. The first control experiment was conducted to put an upper bound on the
571 magnitude of induced blur necessary for the buzz-wire task performance to significantly depart from
572 the baseline no-blur viewing condition. Towards this end, 6 participants repeated the buzz-wire task
573 (three of whom were already part of the main experiment) with the following magnitudes of
574 isometric spherical blur introduced before their eyes in randomized order: 1.25 D, 2.25 D, 3.25 D,
575 4.25 D, 5.25 D and 6.25 D. All other details were the same as the main experiment.

576
577 The averaged data of the 6 participants (Figure S1, top row) and the individual data of each participant
578 (Figure 7, 2nd to 7th rows) shows a trend of increasing error rates (Figure S1, left column) and error
579 duration (Figure S1, middle column) with increasing magnitudes of induced spherical blur in the
580 binocular buzz-wire task. Speed did not appear to be altered with increase in the spherical blur (Figure
581 S1, right column). One-factor RM-MANOVA showed a significant main effect of blur magnitude on the
582 combined outcome variables ($p < 0.001$). Univariate analyses confirmed that this effect was due to the
583 worsening of the error rate ($p = 0.003$) and error duration ($p < 0.001$). Post-hoc Bonferroni analyses
584 revealed significant difference in performance between baseline viewing and with 6.25D of induced
585 blur (error rate: $p = 0.04$; error duration: $p = 0.003$). No other pairwise comparisons reached statistical
586 significance.



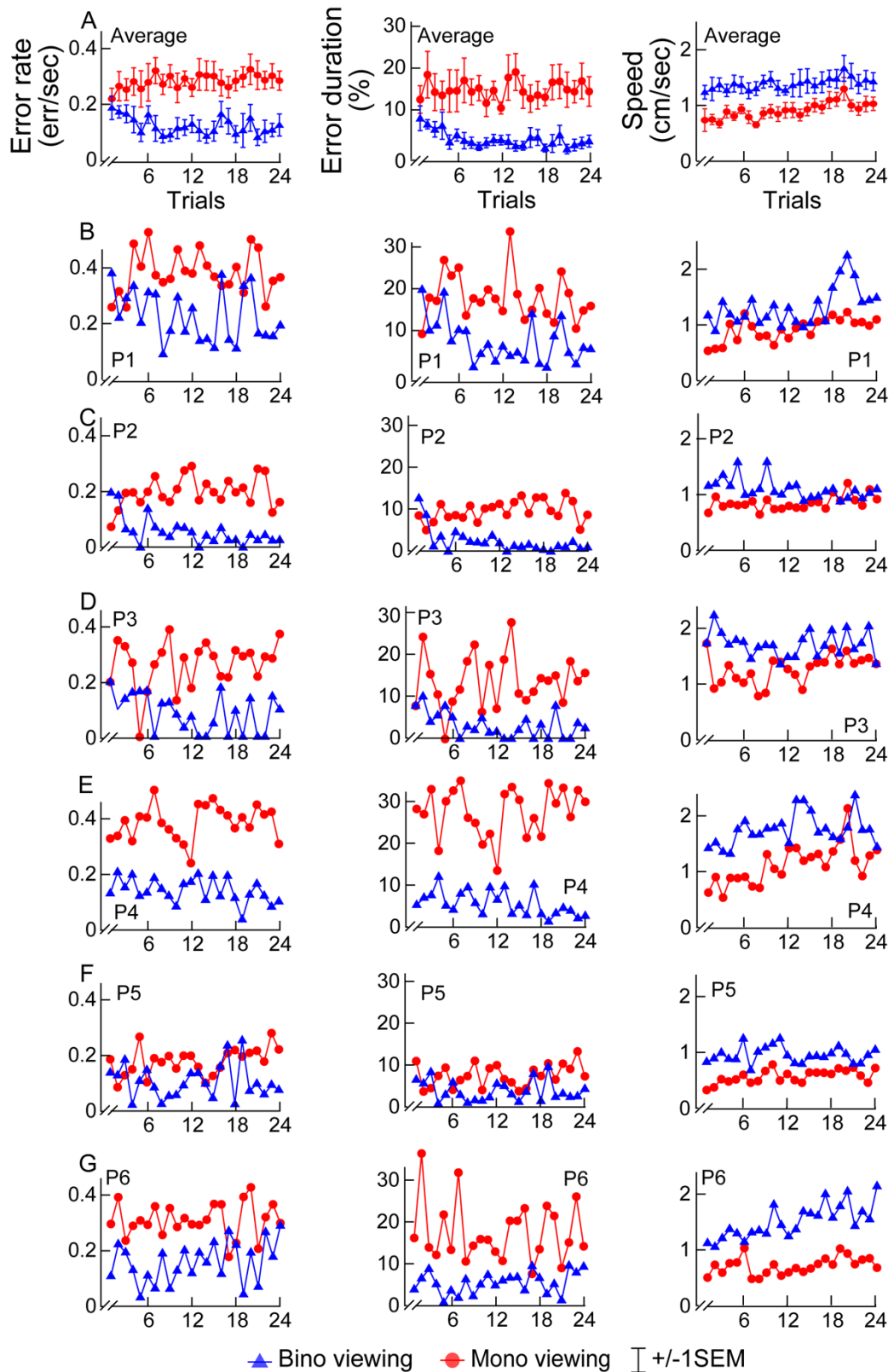
587
 588 **Figure S1:** Error rate (panel A), error duration (panel B) and speed (panel C) plotted as a function of the induced
 589 isometric spherical blur in the first control experiment of this study. The top row shows average data across all
 590 participants, and the remaining rows show data from the individual participants. The lines connecting the dots
 591 are included only to help readers easily follow the data trends across different trials. The error bars in the top row
 592 represent the ± 1 SEM across the mean data of all participants, while they represent the ± 1 SEM across the three
 593 repeated trials in the individual participants.

594

595 *Supplement II*

596 In the main experiment, each participant repeated the buzz-wire task 48 times, even while the order of
597 the experimental conditions was randomized within and across participants. To address the potential
598 impact of practice on the outcome measures, the second control experiment was performed wherein
599 6 new participants repeated the task 24 times each under binocular and monocular viewing conditions
600 using the same buzz-wire pattern. This task was performed with no additional blurring lenses.
601 Participants P1, P2 and P3 performed the task binocularly first while participants P4, P5 and P6
602 performed the task monocularly first. The binocular and monocular versions of the task was performed
603 on two separate days to avoid fatigue. All other details were the same as the main experiment.

604
605 Figure S2 plots the average (panel A) and individual (panels B – G) data of error rate (left column), error
606 duration (middle column) and speed (right column) as a function of the trial number under binocular
607 and monocular viewing conditions. The binocular data qualitatively showed a small improvement in
608 error rate and error durations with increasing trials in the initial (Figure S2), but the 2-factor RM-
609 MANOVA did not show any statistical significance in these trends. Inspection of the individual data
610 reveals that this trend of improvement in task performance was present only in 3 subjects (P1, P2 and
611 P3) and that too only under binocular viewing conditions of the initial trials. Binocular and monocular
612 speed did not show any trend with increasing trial numbers (Figure S2). As expected, the univariate
613 analysis showed statistically significant impact of viewing condition on all three outcome variables ($p \leq$
614 0.007, for all variables).



615

616 **Figure S2:** Binocular and monocular error rate (left column), error duration (middle column) and speed (right
 617 column) plotted as a function of the repeated trials in the second control experiment of this study. The top row
 618 shows average data across all participants and the remaining rows show data from the individual participants.
 619 The error bars in the top row represents the ± 1 SEM across the mean data of all participants across each trial.