

1     **Microsaccades and attention in a high-acuity visual alignment task.**

2                             Rakesh Nanjappa, Robert M. McPeck

3                             *Department of Biological and Visual Sciences*

4                             *SUNY College of Optometry, New York, NY*

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20     Send correspondence to:  
21     Rakesh Nanjappa  
22     SUNY Optometry  
23     Graduate Center for Vision Research  
24     33 West, 42nd street, 17th floor  
25     New York, NY 10036  
26  
27     [rnanjappa@sunyopt.edu](mailto:rnanjappa@sunyopt.edu)  
28

29 **ABSTRACT**

30 While aiming and shooting, we make tiny eye movements called microsaccades that shift gaze  
31 between task-relevant objects within a small region. However, in the brief period before pressing  
32 trigger, microsaccades are suppressed. This might be due to the lack of the requirement to shift  
33 gaze as the retinal images of the two objects start overlapping on fovea. Or we might be actively  
34 suppressing microsaccades to prevent any disturbances in visual perception caused by  
35 microsaccades around the time of their occurrence and their subsequent effect on shooting  
36 performance.

37 In this study we looked at microsaccade rate while participants performed a simulated  
38 shooting task under two conditions: normal viewing in which they moved their eyes freely and  
39 eccentric condition in which they maintained gaze on a fixed target while performing shooting task  
40 at 5° eccentricity. As expected, microsaccade rate dropped at the end of the task in the normal  
41 viewing condition. However, we found the same for the eccentric condition in which microsaccade  
42 did not shift gaze between the task objects.

43 Microsaccades are also produced in response to shifts in covert attention. To test whether  
44 disengagement of covert attention from eccentric shooting location caused the drop in  
45 microsaccade rate, we monitored participant's spatial attention location by employing a RSVP  
46 task simultaneously at a location opposite to the shooting task. Target letter detection at RSVP  
47 location did not improve during the drop in microsaccade rate, suggesting that covert attention  
48 was maintained at the shooting task location.

49 We conclude that in addition to their usual gaze-shifting function, microsaccades during  
50 fine acuity tasks might be modulated by cognitive processes other than spatial attention.

## 51 INTRODUCTION

52 We use rapid eye movements known as saccades to shift our gaze serially between multiple  
53 regions of interest (ROIs) in our visual field, which then guides subsequent motor behaviors like  
54 navigating, or reaching and grasping objects. The amplitude of these saccades during viewing  
55 of a particular scene depends on the separation between ROIs in that scene. In natural scenes,  
56 ROIs are widely spread out, and thus we typically make saccades that are 4° or larger (Dorr,  
57 Martinez, Gegenfurtner, & Barth, 2010). However, in some tasks that require high visual acuity,  
58 like threading a needle or aiming a rifle, ROIs may be separated by distances of less than 1°. In  
59 such tasks, we use saccades as small as 20 minutes of arc to shift gaze precisely and to  
60 explore a narrow range of space. These small saccades can then be used to guide fine motor  
61 adjustments, just as larger saccades do (Ko, Poletti, & Rucci, 2010). Saccades falling in this  
62 small range, known as microsaccades, enjoy a special status in the field of eye movements for  
63 reasons different from their exploratory nature described above: microsaccades are also  
64 produced at a rate of 1-2 per second while trying to hold gaze on a fixation target. The possible  
65 function of these fixation saccades has been a matter of debate (e.g., Collewyn & Kowler, 2008;  
66 Rolfs, 2009). In the contexts of both exploration and fixation, modulations in the spatiotemporal  
67 properties of microsaccades have been shown to reflect different phenomena. Although  
68 changes in microsaccade rate and direction during fixation reflect shifts of covert attention  
69 (Hafed & Clark, 2002; Engbert & Kliegl, 2003a), their most obvious function, that of relocating  
70 gaze, is uncovered only in high visual acuity tasks. When it is necessary to precisely explore a  
71 narrow region of space, such as when threading a needle, both the average and the  
72 instantaneous microsaccade rates are suppressed (Winterson & Collewyn, 1976; Bridgeman &  
73 Palca, 1980; Ko et al., 2010). This observation has led to opposing interpretations regarding the  
74 effect of microsaccades on task performance, and their role in general.

75 Winterson & Collewyn (1976) recorded the eye movements of human subjects while they  
76 performed two separate fine acuity visuo-motor tasks: threading a needle and shooting a rifle.  
77 They made two important observations in both tasks: first, average microsaccade rate during  
78 these tasks was lower than during prolonged fixation on a fixation target. Second, within the  
79 time course of a trial, microsaccade rate decreased with time, with almost no microsaccades  
80 made in the final second of the task, i.e., just before subjects inserted the thread in the eye of  
81 the needle or pressed the rifle trigger. Based on these observations, they concluded that  
82 microsaccades are detrimental to performance in tasks requiring high visual acuity and are thus  
83 suppressed. Similar conclusions were drawn by another study which asked subjects to  
84 passively view the motion of a needle and thread (without any motor control), and to make a

85 perceptual judgment about their alignment (Bridgeman & Palca, 1980). Thirty years later, Ko et  
86 al. (2010) designed a simulated version of the needle-and-thread task in which subjects freely  
87 viewed the task stimulus on a monitor and controlled the vertical position of a thread  
88 approaching a fixed needle at a constant horizontal velocity. They made the same two  
89 observations regarding microsaccade rate, but drew different conclusions. First, they suggested  
90 that microsaccades produced during attempted fixation served a different purpose than those  
91 produced during the needle-and-thread task, and hence their comparison cannot be used to  
92 draw any conclusions. Second, through a detailed spatial analysis of the microsaccades  
93 produced during an earlier period in the trials, they showed that microsaccades precisely  
94 relocated gaze according to the temporally changing separation between the ROIs, and thus  
95 served the dynamic needs of gaze relocation over a very narrow region. Based on this, they  
96 hypothesized that microsaccade rates dropped at the end of the trial not because they were  
97 detrimental to the task, but because at that point, both ROIs overlapped on the effective foveal  
98 region, thus obviating the need for any further gaze shifts.

99 In our present study, we simulated a shooting task in which subjects controlled the  
100 motion of a gun sight so as to align its center with the center of a stationary shooting target. To  
101 study the effects of microsaccades' gaze-relocating function on their rate, we dissociated the  
102 gaze-relocating function of microsaccades from their occurrence by asking subjects to perform  
103 the same task in two different viewing conditions. In the normal viewing condition, as usual,  
104 microsaccades shifted gaze according to the ongoing demands of the task, and their rate  
105 dropped at the end of the trial, as reported in earlier studies. In an eccentric viewing condition,  
106 subjects maintained fixation on a central fixation target while the shooting task stimuli were  
107 presented at a 5° eccentric location. As a result, subjects used peripheral vision to view the task  
108 stimulus, and thus, any microsaccades produced during the task could not serve the purpose of  
109 relocating the fovea between the peripherally-viewed ROIs. Nevertheless, we observed a similar  
110 drop in microsaccade rate. This suggests that there is something other than a gaze-relocation  
111 demand which suppresses microsaccades during the end of the eccentric viewing task. We  
112 speculated that this decrease in saccades in the eccentric viewing task may reflect the  
113 disengagement of attention from the peripheral shooting task stimuli. However, in a final  
114 experiment, we tested this explanation, and found that the drop in microsaccade rate in the  
115 eccentric viewing condition does not appear to reflect a release of attentional disengagement  
116 from the peripherally-attended task location. Put together, our findings suggest that  
117 microsaccade production in such tasks is affected by factors other than just their gaze-

118 relocation function, and that the exact cause of their suppression remains a topic for future  
119 research.

120

## 121 **METHODS**

### 122 **Participants**

123 Seven (4 female) students from the Graduate Center for Vision Research, SUNY College of  
124 Optometry, with normal or corrected to normal vision and no known oculomotor defects, ranging  
125 in age from 25-30 years, participated in Experiment 1. Five of these subjects also participated in  
126 Experiment 2. Each participant signed a consent form approved by the SUNY College of  
127 Optometry Institutional Review Board. Participants received a base payment of \$10 per  
128 experimental session plus an additional amount contingent upon their performance in the task,  
129 with the total payment not exceeding \$20 for a single session. Although participants were not  
130 totally naïve about the purpose of the study, they did not have any prior experience of participating  
131 in a similar task or one which could have altered their microsaccade strategy in a fine acuity  
132 visuomotor task.

133

### 134 **Task**

135 Participants sat 120 cm away from an IPS LCD monitor (Cambridge Research Systems  
136 Display++; 71 x 39.5 cm, 1920 x 1080 pixels, refresh rate 120 Hz, gray background) in a room  
137 with ambient lighting. Their heads were stabilized with a chin and forehead rest, and monocular  
138 eye movements (left eye for all participants) were recorded using an EyeLink 1000 (SR Research)  
139 at 1000Hz.

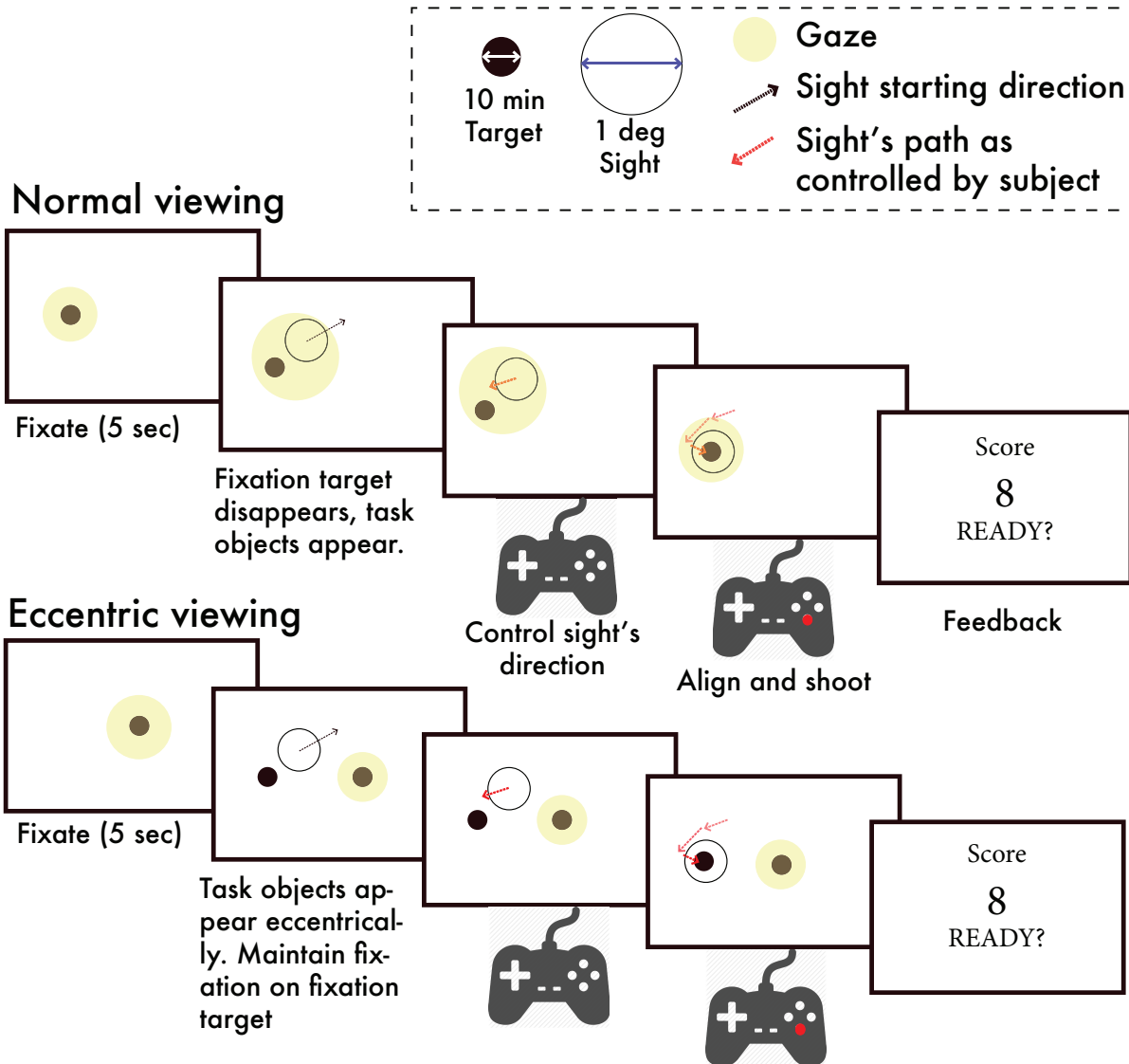
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141 *Experiment 1:* Participants performed a simulated shooting task under two viewing conditions,  
142 each in a separate session consisting of 120 trials and lasting for ~40 minutes, conducted on  
143 separate days. Each session began with a practice block in which participants performed 20 trials  
144 to become familiarized with the task and the associated push-button controls. After the practice  
145 block, the eye tracker was calibrated using EyeLink's standard 9-point calibration. In the first  
146 condition, viz., the normal viewing condition, each trial started with the presentation of a 10' wide  
147 black circular fixation target at the center of the screen (**Fig. 1**). Participants maintained fixation  
148 on the fixation target for a duration of 5 seconds, during which they were instructed not to blink.  
149 A blink resulted in termination of the trial, and a fresh trial began. After this prolonged fixation  
150 period, the fixation target disappeared and the shooting target (a black disc subtending 10')  
151 appeared at one of 5 possible positions (0°, 5° left/right, 3° up/down), along with the 'sight' (a

152 black circle outline of diameter  $1^\circ$  and boundary width  $1.4'$ ) within close vicinity of the shooting  
153 target. The starting position of the sight was randomly picked from an invisible square boundary  
154 of length  $1.5^\circ$  centered on the shooting target. Immediately after presentation, the sight started to  
155 move in a randomly-selected diagonal direction ( $45^\circ$ ,  $135^\circ$ ,  $225^\circ$ , or  $315^\circ$  in direction with respect  
156 to the target) with a fixed velocity (randomly selected to be 9, 12, 13 or 15 min/sec). Participants  
157 used 4 direction buttons on a gamepad to control the sight's direction of motion (which was  
158 constrained to the four directions listed above). The goal was to align the center of the moving  
159 sight with the center of the fixed shooting target. A single button press resulted in a corresponding  
160 change of direction (e.g., pressing the left button set the horizontal component of the motion to  
161 the left) with no change in overall speed. Participants pressed a 'shoot' button on the gamepad  
162 when they judged the centers of the two objects to be perfectly aligned. Following this 'shoot'  
163 event, the task stimuli disappeared, and performance on the trial was reported at the location of  
164 the fixation point as a score (out of 10) calculated based on the distance of the sight center from  
165 that of the target. Task eccentricity and sight velocity for each trial were picked randomly, and  
166 with equal probability, from the discrete values listed above.

167 In the second condition, viz., the eccentric viewing condition, a trial started with a 1-second  
168 fixation period, after which the shooting target and sight appeared at one of the four eccentric task  
169 locations ( $5^\circ$  left/right,  $3^\circ$  up/down), while the fixation target remained on the screen. As opposed  
170 to the previous condition, in which participants were free to move their eyes, subjects were now  
171 instructed to maintain fixation on the central fixation target, and to use their peripheral vision to  
172 accomplish the same task (i.e., to align the sight center with the target center and shoot). Fixation  
173 was monitored using a fixation-check window, which consisted of an invisible square boundary of  
174 length  $2^\circ$  centered on the fixation target. A trial was aborted if the eye moved out of this window,  
175 or if the participant blinked. Participants could take a maximum of 30 seconds to finish a trial, and  
176 they controlled the beginning of the next trial with a button press. Calibration was re-done between  
177 trials if subjects moved their heads significantly. A session ended with completion of 120 valid  
178 trials.

179 *Experiment 2:* This experiment consisted of a dual-task situation, in which participants performed  
180 the same simulated shooting task as in Experiment 1, while simultaneously performing a task that  
181 required detecting a target letter from a stream of rapidly and serially presented letters (Rapid  
182 Serial Visual Presentation [RSVP] task). The RSVP stream consisted of  $1^\circ$  wide letters of the  
183 English alphabet, presented at a frequency of 5 Hz. The letter stream for each trial consisted of a



184

185 **Figure 1. Experiment design.** In Experiment 1, during the normal viewing condition, a trial started with  
186 fixation on a central fixation target for 5 sec, followed by presentation of shooting task stimuli, during which  
187 participants were free to move their eyes, and adjusted the sight's direction of motion using a gamepad.  
188 The yellow patch shows the likely gaze position of the subject. The black arrow shows the initial motion  
189 path of the sight and the red arrows shows the motion path after a participant adjusted its direction. After  
190 aligning the sight's center to the center of the shooting target they pressed the 'shoot' button on the  
191 gamepad to end the trial, following which their performance in that trial was reported to them as a score out  
192 of 10. In the eccentric viewing condition, everything was similar except that shooting task stimuli always  
193 appeared at an eccentric location and participants were required to maintain their fixation on the central  
194 fixation target while viewing the shooting task stimuli using peripheral vision. Score was presented at the  
195 fixation location.

196

197 random sequence of non-target letters, with the target letter interspersed such that target letter  
198 frequency was 0.5 or 0.8 Hz. The target letter remained the same for a given session. Participants  
199 reported detection of a target letter by pressing a button on the gamepad as soon as they saw it.



200 They performed this dual task under two viewing conditions with respect to viewing of  
201 the shooting stimuli. In the normal viewing condition (50% of trials), the shooting stimuli  
202 appeared at the center of the screen, where subjects were fixated, and the RSVP task stimuli  
203 appeared at one of two eccentric locations (5° left/right), and were viewed peripherally. In the  
204 eccentric viewing condition, participants maintained fixation on the central fixation target while  
205 the shooting and RSVP task stimuli appeared at eccentric locations on opposite sides of  
206 fixation. Again, fixation was monitored used a fixation-check square window of length 4°  
207 centered at the central fixation location, and a trial was aborted if participants blinked or moved  
208 their eyes out of this boundary. Participants adjusted the sight's direction of motion as before,  
209 using the 4 direction buttons, and reported RSVP target detection using another button. Finally,  
210 they pressed the 'shoot' button when they judged the sight and target to be aligned. Following  
211 this, both task stimuli disappeared, but instead of the trial ending immediately, an extra 1  
212 second was made available to report any last-moment RSVP target detection made by subjects.  
213 Following this, their shooting performance and RSVP task performance (percentage target letter  
214 detection) were reported to them at the location of fixation.

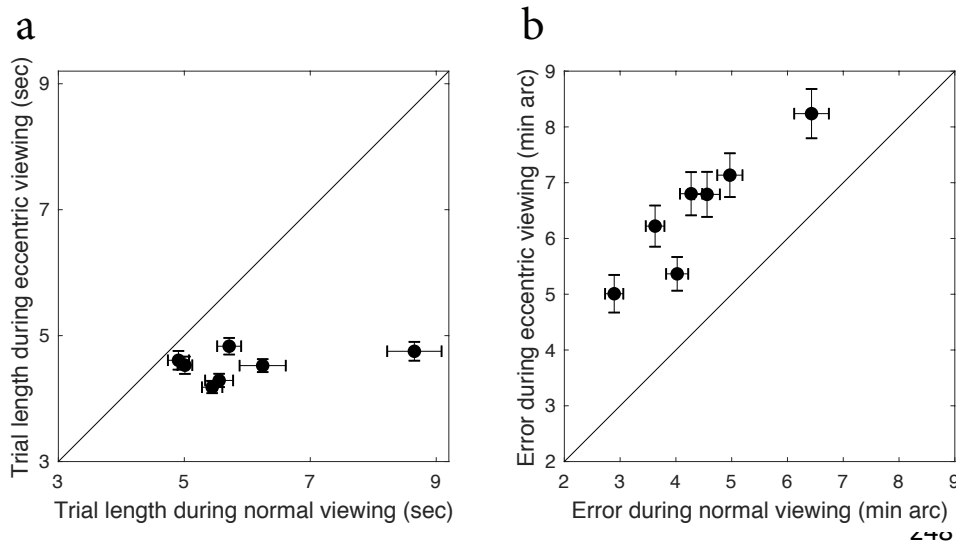
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## 216 RESULTS

217 In a simulated shooting task, participants used a gamepad to align the center of a moving circle  
218 (hereafter referred to as the 'sight,' as in the gun sight through which shooters view the shooting  
219 target to take an aim) with that of a fixed target disc (referred to as the shooting target). A trial  
220 started with the sight moving diagonally in a random direction with a constant velocity, with an  
221 initial separation of 1° between the target and sight (two regions of interest [ROIs]). Participants  
222 adjusted the sight's direction of motion so as to align its center with that of the target, and then  
223 'shot' by pressing a 'shoot' button at a time when they perceived the centers of the two objects to  
224 be perfectly aligned. They performed this task under two conditions of viewing: (i) normal viewing,  
225 in which participants were free to move their eyes anywhere on the screen, and (ii) eccentric  
226 viewing, in which they maintained fixation on a central fixation target and viewed the task stimuli  
227 with their peripheral vision. In the normal viewing condition, each trial was preceded by a 5 second  
228 long fixation period on the central fixation target which was used as a control condition.

229 Participants took a longer time before shooting, but performed better when they viewed  
230 the task stimuli normally as compared to when they used their peripheral vision. In the normal  
231 viewing condition, they finished a trial in  $5.93 \pm 1.28$  sec (mean  $\pm$  s.d.) whereas they took only  
232  $4.53 \pm 0.23$  sec in the eccentric viewing condition (paired t-test,  $t(6) = 3.07$ ,  $p = 0.02$ , **Fig. 2a**).





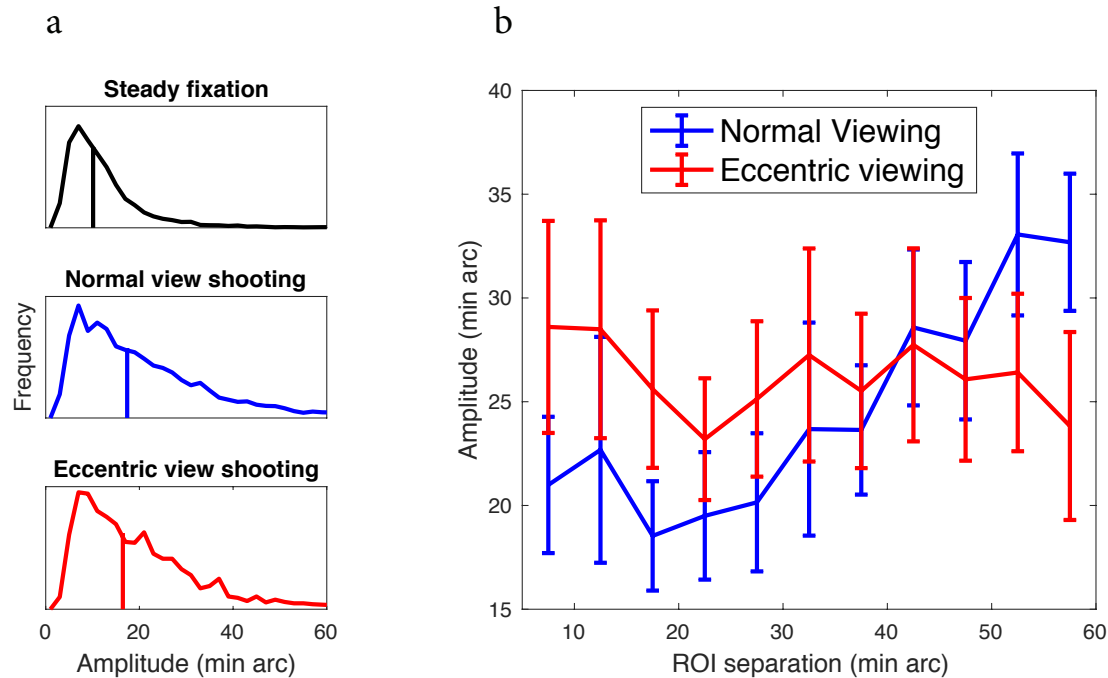
**Figure 2. Time taken to shoot, and performance under normal and eccentric viewing conditions.** (a) Each data point shows the mean time taken by a single participant to complete a trial under the two viewing conditions (n=7). Error bars represent s.e.m. (b) Each point shows for a single participant the mean error in alignment

249 of the centers of the shooting target and sight when subjects pressed the “shoot” button, under the two  
250 viewing conditions.

251  
252 Shooting error (distance between the center of the target and the center of the sight) was  $4.37 \pm$   
253  $1.19$  minutes of arc in the normal condition, whereas it was  $6.51 \pm 1.09$  minutes of arc in the  
254 eccentric condition (paired t-test,  $t(6) = -12.99$ ,  $p < 0.01$ , **Fig. 2b**).

255 The distribution of microsaccade amplitudes was also affected by task condition (Kruskal-  
256 Wallis test,  $H = 1660.72$ ,  $df = 2$ ,  $p < 0.01$ ; **Fig. 3a**): specifically, participants made larger  
257 microsaccades when they performed the shooting task compared to when they just fixated on a  
258 fixation target (Tukey’s HSD,  $p < 0.01$ ). On the other hand, there was no significant difference  
259 between the distribution of microsaccade amplitudes under the two viewing conditions of shooting  
260 ( $p = 0.2$ ). To verify whether microsaccades were used to shift gaze between the two ROIs during  
261 the shooting task, we compared microsaccade amplitude as a function of the separation between  
262 the ROIs at beginning of each microsaccade. In the normal viewing condition, microsaccade  
263 amplitude was strongly correlated with ROI separation (**Fig. 3b**;  $r = 0.87$ ,  $p < 0.01$ ), which  
264 suggests that participants calibrated their microsaccade length to shift gaze between the ROIs.  
265 In the eccentric viewing condition, it is not possible to align gaze with the target or the sight, and,  
266 correspondingly, microsaccade amplitude was not correlated with the separation between ROIs  
267 ( $r = -0.36$ ,  $p = 0.27$ ).

268



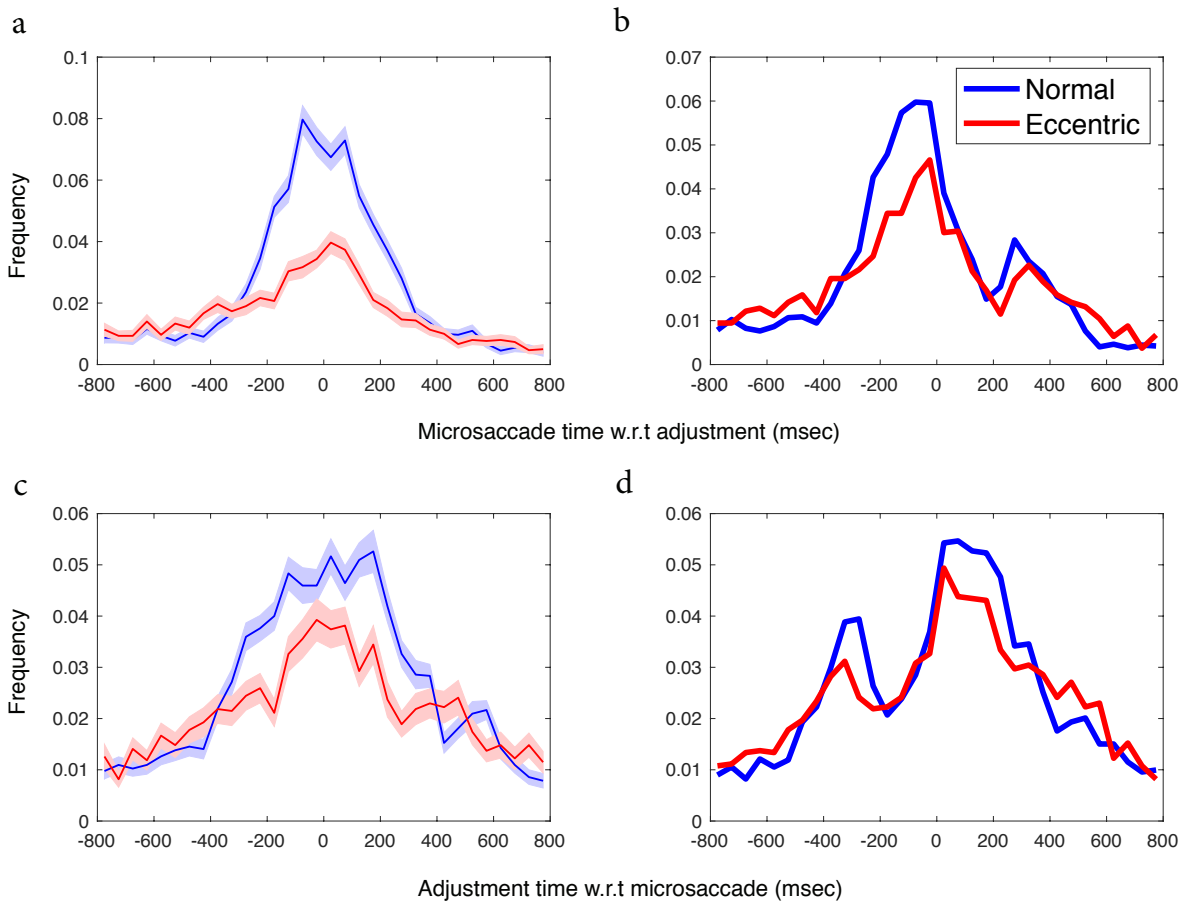
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270 **Figure 3. Comparison of microsaccade amplitude.** (a) Microsaccade amplitude distribution for the  
271 different task conditions. The vertical lines show the median amplitude for each condition. (b) Microsaccade  
272 amplitude as a function of the separation between regions of interest at the time of execution of  
273 microsaccade. Error bars represent s.e.m.

274

275 We were interested to see whether there existed any temporal relationship between  
276 microsaccade occurrence and sight adjustment (through button press) events. For a given sight  
277 adjustment within a given trial, we subtracted all microsaccade starting times for that trial from the  
278 sight adjustment time and chose the one with the minimum absolute value as the microsaccade  
279 nearest to this sight adjustment in time. We did this for all sight adjustments within each viewing  
280 condition and obtained the corresponding distribution of nearest microsaccade times in relation  
281 to all sight adjustments (blue and red solid traces in **Fig. 4b**). A positive value means that a  
282 microsaccade followed the sight adjustment in time, while a negative value means that the  
283 microsaccade preceded the sight adjustment.

284



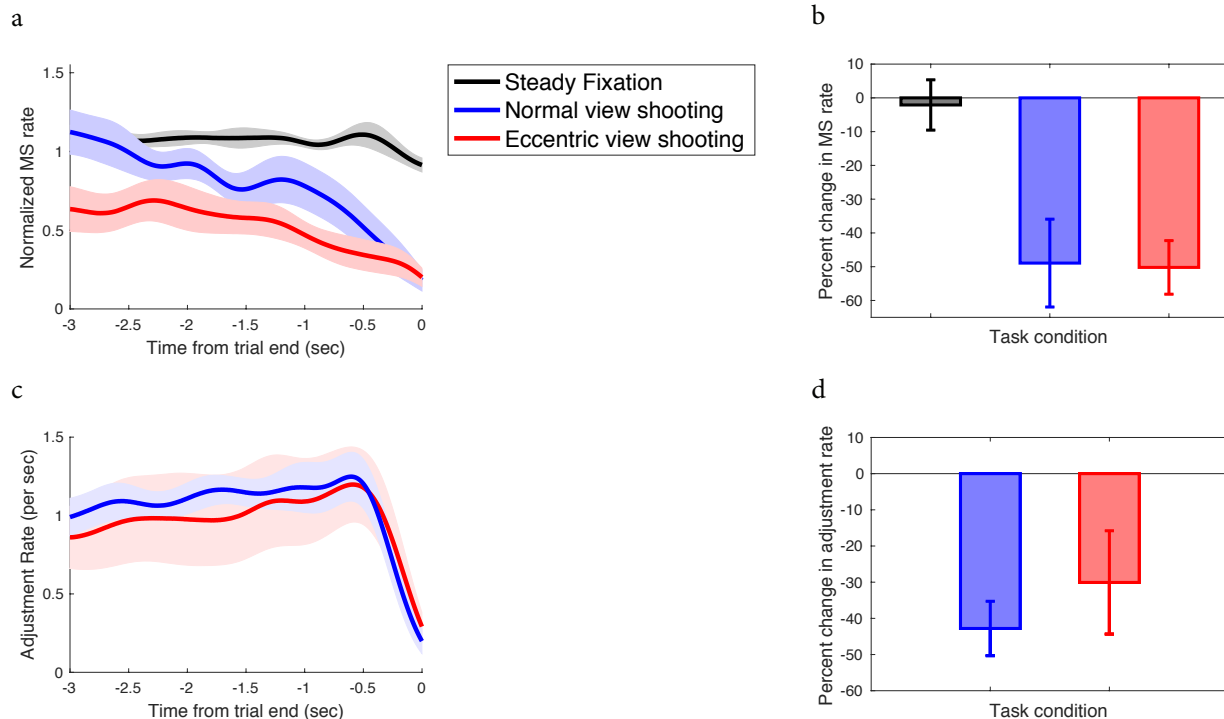
285 **Figure 4. Temporal relation between microsaccade occurrence and sight adjustment times (button**  
286 **presses).** (a) Solid lines show the mean of distribution of nearest pseudo-microsaccade times w.r.t each  
287 adjustment. Shaded area represents s.e.m. Blue: Normal viewing condition, Red: Eccentric viewing  
288 condition. (b) Distribution of nearest real-microsaccade times w.r.t to each adjustment. (c) Solid lines show  
289 the mean of distribution of nearest pseudo-button-press time w.r.t to each microsaccade, shaded region  
290 shows s.e.m. (d) Distribution of nearest real button-press times w.r.t each microsaccade.  
291

292 For comparison, we repeated the above calculation with pseudo-microsaccades (**Fig. 4a**): a set  
293 of random time points across the duration of each trial. The number of such random points for a  
294 trial was same as the number of microsaccades in that trial. We repeated this process 100 times  
295 to get 100 frequency distributions of nearest pseudo-microsaccade times with respect to sight  
296 adjustment times. The probability of a microsaccade preceding an adjustment was higher in the  
297 time period ~200 msec before an adjustment, whereas the probability of a microsaccade following  
298 an adjustment dropped during ~200ms time period following an adjustment. This observation was  
299 true for both conditions. Similarly, we created distribution of adjustment time nearest to each  
300 microsaccade by subtracting each sight adjustment time from the microsaccade start time and  
301 picking the one with minimum absolute value as the sight adjustment nearest to this microsaccade

302 in time (**Fig. 4d**). We compared this distribution with the distribution of pseudo-adjustment times  
303 computed as mentioned above for pseudo-microsaccade times (**Fig. 4c**). For both conditions, the  
304 probability of an adjustment dropped in the time period ~200 msec preceding a microsaccade,  
305 whereas the probability of an adjustment increased in the time period ~200 msec following a  
306 microsaccade. The two findings suggest that irrespective of the different viewing conditions,  
307 microsaccade and sight adjustment through button presses were temporally related, with  
308 adjustments remaining suppressed during the 200 msec time preceding a microsaccade, and  
309 occurring with a higher probability in the ~200 msec following a microsaccade.

310 Next, we compared mean microsaccade rate near the end of the shooting task for the two  
311 viewing conditions by aligning each trial's microsaccade rate function to trial end (**Fig 5a**). In the  
312 normal viewing condition, mean microsaccade rate in the final second of the task was significantly  
313 lower than in the third second before trial end (one tailed paired t-test,  $t(6) = -3.34$ ,  $p < 0.01$ , **Fig.**  
314 **5b**). This drop in microsaccade rate near the end of the shooting task agrees with the results of  
315 previous studies (e.g., Bridgeman & Palca, 1980; Ko, Poletti, & Rucci, 2010; Winterson &  
316 Collewun, 1976), and has been attributed to the lack of a need to shift gaze as the ROIs start to  
317 overlap on the effective foveal region (Ko et al., 2010). Surprisingly, mean microsaccade rate also  
318 decreased toward the end of the trial during the eccentric viewing condition ( $t(6) = -4.91$ ,  $p < 0.01$ ),  
319 even though in this task, microsaccades could not function to shift gaze between the relevant task  
320 objects. This indicates that in the shooting task, microsaccade rate is modulated toward the end  
321 of the trial in a similar way, irrespective of whether they performed a gaze orientating function (as  
322 in the normal viewing condition) or not (as in the eccentric viewing condition). For comparison, we  
323 also analyzed microsaccade rate during the fixation task. Since the end of the 5-second fixation  
324 period was followed by a shooting task trial, we selected a 3-second time period from the middle  
325 of each fixation trial for analysis. This avoided possible modulations in microsaccade rate due to  
326 the anticipated onset of the subsequent trial. Microsaccade rate during fixation period remained  
327 unchanged ( $t(6) = -0.48$ ,  $p = 0.32$ ).

328 If the earlier reported and currently observed drop in microsaccade rate at the end of  
329 shooting task is because of the two ROIs finally overlapping on the same effective foveal region  
330 and thus making the need to shift gaze obsolete or even harmful for the task, then what could  
331 have caused the drop in microsaccade rate in the eccentric viewing condition, when  
332 microsaccades did not occur to overtly shift gaze between the relevant task objects? One  
333 possibility is that this drop in microsaccade rate may be related to a change in the allocation of  
334 covert spatial attention near the end of the trial.

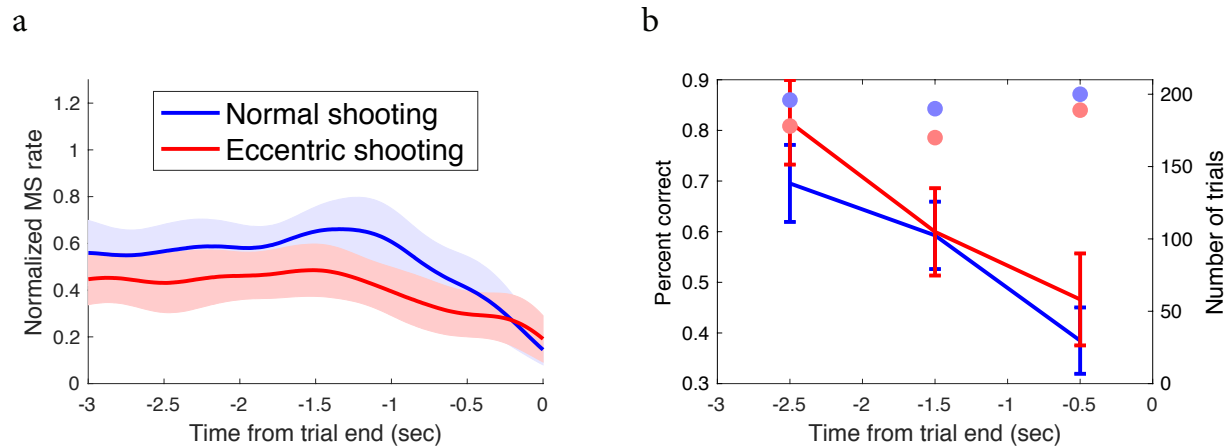


335  
336 **Figure 5.** Mean microsaccade and adjustment (button press) rate aligned to trial end. (a) Solid lines show  
337 average of all participants' mean normalized microsaccade rate during steady fixation (black), shooting  
338 under normal viewing (blue) and eccentric viewing (red), aligned to trial end. Shaded region indicates s.e.m.  
339 (b) Percent change in microsaccade rate from early period (-3 to -2 sec from trial end) to the end period  
340 (last 1 sec). Error bars represent s.e.m. Color coding of bars is same as in panel (a). (c) Rate of button  
341 presses resulting in adjustment of sight's direction; aligned to trial end. (d) Percent change in adjustment  
342 rate from an early time (-1 to -0.5 sec from trial end) to trial end (last 0.5 sec). Color coding in (b), (c), and  
343 (d) same as in (a).  
344

345 Microsaccades have been shown to reflect shifts in covert attention (Engbert & Kliegl,  
346 2003b). Immediately following a covert shift of attention, microsaccade probability increases and  
347 their directions tend to align with the direction of the newly attended location. Based on this, one  
348 possible explanation for the observed drop in microsaccade rate during eccentric viewing  
349 condition could be this: during the initial phase of the trial, participants constantly switch attention  
350 alternatively between the central fixation target and eccentric task location, and the  
351 microsaccades thus produced are reflective of this phenomenon. Nearing the end of trial, at a  
352 certain time before actually pressing the shoot button, participants may stop assessing the  
353 alignment between the shooting stimuli as the poor quality of peripheral vision does not afford fine  
354 judgement of the alignment of the two objects. Thus, participants pre-decide when to shoot and  
355 disengage attention from the eccentric task location before the end of the task, and this is reflected  
356 by the decrease in microsaccadic activity at the end. We conducted the next experiment to test  
357 this hypothesis.

358 In a dual attention task, participants detected a peripheral target letter from a rapid stream  
359 of letters (RSVP task; Rapid Serial Visual Presentation), while simultaneously performing the  
360 same shooting task as before. They viewed the shooting stimuli under the same two conditions  
361 as earlier; normal and eccentric. The RSVP stimuli appeared at an eccentric location in both  
362 conditions, and, for the eccentric viewing condition, this location was always in the hemifield  
363 opposite the shooting stimuli. If the attentional disengagement hypothesis is true, then in the  
364 eccentric viewing condition, it would be expected that performance in the RSVP task would  
365 improve at end of the trial as attention is disengaged from shooting task and is readily available  
366 to be allocated to RSVP task location.

367 Microsaccade rates showed a similar pattern as during the first experiment, with their rate  
368 decreasing significantly in the later part of the trial for both the normal and eccentric viewing  
369 conditions (**Fig 6a**). However, RSVP task performance did not improve toward the end of the trial  
370 in the eccentric viewing condition (**Fig 6b**). Instead, it deteriorated with time until the end of the  
371 trial for both conditions. This suggests that attentional disengagement from the shooting target  
372 location is not the explanation for the observed drop in microsaccade rate at the end of the trial  
373 in the eccentric viewing condition.



374 **Figure 6.** RSVP Performance in dual task. (a) Mean normalized microsaccade rate aligned to trial end for  
375 shooting under normal viewing (blue) and eccentric viewing (red) in the dual task. RSVP task was at an  
376 eccentric location in both conditions, and opposite to shooting location in the eccentric shooting condition.  
377 Shaded regions represent s.e.m. (b) Target letter detection in RSVP task under the two viewing conditions  
378 of shooting in dual task. Color coding same as in (a). Error bars represent s.e.m. Colored dots in each time  
379 bin indicate the total number of trials in which RSVP target appeared at corresponding times. Blue; normal  
380 shooting condition, red; eccentric shooting condition.

## 382 **DISCUSSION**

384 While performing tasks requiring fine acuity like shooting or threading a needle, microsaccades  
385 initially shift gaze precisely between the task relevant objects over a very narrow range of the

386 visual field ( $< 1^\circ$ ; Ko, Poletti, & Rucci, 2010), just like bigger saccades (Otero-Millan, Macknik,  
387 Langston, & Martinez-Conde, 2013), and during the final second of the task their rate drops  
388 drastically, with no microsaccades at all in most of the trials (Winterson & Collewun, 1976;  
389 Bridgeman & Palca, 1980; Ko et al., 2010). This drop in microsaccade rate within a trial, along  
390 with the lower average rate during a task, as compared to during fixation, had initially been  
391 explained as a voluntary suppression of microsaccades to avoid their effects on visual perception,  
392 which could deteriorate performance (Winterson & Collewun, 1976). But a more recent study (Ko  
393 et al., 2010) suggested that as the relevant task objects start to overlap in the foveal region, the  
394 need to shift gaze is obviated, resulting in a drop in their rate.

395 Here, we asked human participants to perform a simulated shooting task in a normal  
396 viewing condition, in which they were free to move their eyes, and in an eccentric viewing  
397 condition, in which they fixated on a central target while performing the same task at an eccentric  
398 location. The two different conditions dissociated the gaze-reorienting function of microsaccades,  
399 as microsaccades made at the fixation location in the eccentric condition could be spontaneous  
400 or a result of sustained covert attention (Pastukhov, Vonau, Stonkute, & Braun, 2013), but could  
401 not reorient gaze between the shooting task stimuli. Thus, any modulation in microsaccade rate  
402 in this condition would be independent of its gaze-orienting function. For the normal shooting  
403 condition, we replicated the findings of earlier studies. Surprisingly, even for the eccentric  
404 condition, microsaccade rate showed a fairly abrupt drop during the final second of the task (Fig.  
405 5), indicating that subjects suppressed microsaccades even when they did not shift gaze between  
406 the task relevant objects. Although the drop in microsaccade rate in the normal viewing condition  
407 can be explained by the demand of dynamic gaze shifts fulfilled by microsaccades (Ko et al.,  
408 2010), it does not explain why such a drop would be observed in the eccentric viewing condition.  
409

410 Possible explanations for the observed drop in microsaccade rate in our study are: spatial  
411 disengagement of covert attention from eccentric task location, active suppression to improve  
412 task performance, preparation or execution of oculomotor (saccade towards eccentric task  
413 location to judge task performance after the task ends) or manual (key press to 'shoot') response,  
414 perceptual decision making process, temporal expectation, and changes in temporal attention.  
415 We will go through these possibilities one by one.

416 Participants performed the shooting task less accurately in the eccentric condition (Fig.  
417 2), consistent with poorer localization of the task stimuli when viewed in peripheral vision. Hence  
418 it is possible that they focused more on the initial coarser adjustments of the gun sight and then  
419 pressed the trigger at a pre-planned time based on the sight's velocity information, without making



420 final fine adjustments. Since participants in this condition fixated a central target while covertly  
421 paying attention to the eccentric task location, microsaccades produced initially in a trial could  
422 have been the result of alternating attention between the fixation target and eccentric task  
423 location, as it has been shown by both psychophysical (Engbert & Kliegl, 2003a; Hafed & Clark,  
424 2002; Hafed, Lovejoy, & Krauzlis, 2011; Pastukhov et al., 2013) and electrophysiological (Hafed,  
425 Lovejoy, & Krauzlis, 2013) studies that microsaccade characteristics are related to immediate and  
426 sustained shifts of covert attention. The observed drop in microsaccade rate in the eccentric  
427 viewing condition could have resulted from a disengagement of attention from the peripheral  
428 location toward the end of the task. To test this possibility, we asked subjects to perform the  
429 shooting task under the same two conditions, but with an added RSVP task at an eccentric and  
430 opposite location. If attention was indeed disengaged from the eccentric shooting task location,  
431 then in this dual task situation, we expected greater attention resources would be available to be  
432 captured by the RSVP task location, thus making performance in the RSVP task better when  
433 microsaccade rate decreased in the peripheral task. On the other hand, in the normal condition  
434 we expected no such change in RSVP performance. We found that RSVP performance near the  
435 end of the trial deteriorated in both the conditions (Fig. 6), suggesting that an attentional  
436 disengagement from the shooting stimuli is unlikely to be the explanation for the observed drop  
437 in microsaccade rate. Nonetheless, it is also possible that our RSVP task failed to capture the  
438 disengaged attention or that attention in that short span was, instead, diffused over the entire  
439 field, or that attention was instead focused primarily on the central fixation target. In all such cases  
440 microsaccade rate would still be expected to drop. Carefully designed experiments would be  
441 needed in the future to test each of these specific hypotheses.

442 Our results show that microsaccades are suppressed during the end of the shooting task,  
443 just before fine acuity information is presumably processed to judge the relative alignment of the  
444 target and sight to arrive at a perceptual decision as to when to press the trigger. Like larger  
445 saccades, microsaccades also modulate visual perception around the time of their occurrence,  
446 which could affect task performance adversely (Hafed, Chen, & Tian, 2015). They compress the  
447 perception of both space (Hafed, 2013) and time (Yu, Yang, Yu, & Dorris, 2017). To avoid the  
448 adverse effects of such perceptual modulations on task performance, the oculomotor system  
449 might have learnt to suppress microsaccades at a time when a perceptual decision has to be  
450 made (Bridgeman & Palca, 1980). Hafed et al. (2011) found that on a sustained covert attention  
451 task requiring monkeys to judge the direction of a motion pulse at a cued location, monkeys took  
452 longer to respond and tended to make more errors if a microsaccade occurred near the time of  
453 motion pulse onset. Similarly, Xue et al. (2017) more recently found that in a color change

454 detection task, microsaccades occurring in the period  $\pm 100$  ms around the color change delayed  
455 the monkey's response time and also worsened their detection performance. A lower  
456 microsaccade rate is also correlated with higher accuracy in orientation judgements (Amit, Abeles,  
457 Carrasco, & Yuval-Greenberg, 2019; Denison, Yuval-Greenberg, & Carrasco, 2019). We did not  
458 find any correlation between the timing of the last microsaccade and performance in a trial. Our  
459 failure to find any relation between microsaccade occurrence and task performance could be  
460 because of three reasons: first, as opposed to monkeys, humans participated in our experiment,  
461 and it is possible that humans, through learning, have become more robust in performance in  
462 such tasks. Second, instead of detection, our task required humans to constantly judge the  
463 relative positions of the task objects to finally make a perceptual judgement about when the two  
464 objects were concentric, and then press a trigger. Microsaccades might have impaired the  
465 perceptual view of a stimulus change around their time of occurrence when the response is binary  
466 (yes/no), but they might not affect performance in our task in which performance is judged on a  
467 continuous scale (by how much distance was the target missed?). Finally, even if the occurrence  
468 of microsaccades did affect performance, our experimental design might have failed to capture it  
469 because the number of trials in which microsaccades did occur near the end was smaller than  
470 the number of trials in which there were no microsaccades, and thus, the margin of error may  
471 have been too small to observe any significant difference in performance.

472         Microsaccades are suppressed in preparation of saccades (Rolfs, Laubrock, & Kliegl,  
473 2006; Hermens, Zanker, & Walker, 2010; Watanabe, Matsuo, Zha, Munoz, & Kobayashi, 2013;  
474 Dalmaso, Castelli, & Galfano, 2019) as well as manual responses (Betta & Turatto, 2006). In our  
475 present study, participants did not make a saccade towards the eccentric task objects since we  
476 enforced fixation on the fixation target using an invisible fixation boundary. Also, the shooting  
477 score in any given trial was presented at the fixation target location at the end of the trial, thus  
478 obviating the need to make a saccade towards an eccentric location. Any reflexive saccades  
479 made to the eccentric location terminated the trial even if the participant had already pressed the  
480 'shoot' button, and the number of such trials was very low. Hence our analysis did not include  
481 such trials, and we can rule out the possibility of microsaccades getting suppressed by saccade  
482 preparation. Microsaccades have been shown to be suppressed during needle threading tasks  
483 even in the absence of manual response ((Bridgeman & Palca, 1980; Ko et al., 2010)). In these  
484 studies, participants passively watch a thread approaching the needle until the partial completion  
485 of the trial after which the task stimulus was masked and participants responded orally about their  
486 judgement about whether the thread made it through the needle's eye or not. This allows us to  
487 rule out the possibility of a manual response preparation induced suppression of microsaccades.

488           The only explanations we are left out with are temporal expectation of a visual change and  
489 changes in temporal attention. Amit et al., (2019) showed that microsaccades are inhibited when  
490 a temporal cue is informational about an upcoming target whose orientation has to be judged. In  
491 addition the cue-target interval was also related to the intensity of microsaccade inhibition,  
492 reflecting a microsaccade suppression mechanism driven by anticipation of an event. This could  
493 well be the reason for the suppression of microsaccades in our task since at the end of every trial,  
494 participants anticipated their performance which presented to them in the form of a shooting  
495 score. Although we ruled out the possibility of change in the focus of spatial attention during the  
496 end of the task affecting microsaccade rate, it is possible that a change in temporal attention might  
497 have contributed to the drop in microsaccade rate. Such suppression has been reported recently  
498 in an orientation discrimination task (Denison et al., 2019) in which a temporal cue is informative  
499 about which target among a stream of targets is to be assessed. It is possible that participants in  
500 our study directed their temporal attention more intensely nearing the end of the task in an attempt  
501 to judge the relative position of the target and sight when they were the nearest to each other  
502 which could have caused the suppression of microsaccades.

503           An interesting finding in our study is the tight temporal coupling between the  
504 microsaccades and button presses used to adjust sight direction (Fig. 4). Button presses were  
505 more likely to be executed in the ~200 ms following a microsaccade, whereas microsaccades  
506 were inhibited in the ~200 ms following an adjustment. Two inferences can be drawn from this  
507 observation; first, adjustments were mostly made after a microsaccade was made to judge the  
508 relative position of the target and sight, similar to Ko et al.'s (2010) findings. This provides  
509 evidence to support the idea that microsaccades serve a gaze-shifting function similar to larger  
510 saccades, which is then used to aid manual adjustments of the sight's direction. Second,  
511 microsaccades and button presses always occurred in a particular sequence and not  
512 simultaneously, which suggests that oculomotor and motor (hand) response preparation could  
513 share a common cognitive resource (Betta & Turatto, 2006).

514           There are two limitations to our current study. First, we used a video-based eye tracker  
515 that has a relatively low spatial resolution, significant trial-to-trial variability in its estimate of actual  
516 line of sight (Kimmel, Mammo, & Newsome, 2012), and pupil size change induced artifacts in eye  
517 position signal (Nyström, Hooge, & Andersson, 2016). These factors limited our analysis of  
518 microsaccade directions. Thus, we cannot say with confidence the precise position of the actual  
519 line of sight in the range of the fine resolution of our task stimuli, or the exact task object to which  
520 the microsaccades were directed. Nonetheless our finding of a positive and significant correlation  
521 between the microsaccade amplitude and separation between the task objects only in the normal

522 viewing condition is sufficient to infer that microsaccades were used to shift gaze precisely when  
523 they were free to move their eyes. Second, we assume that microsaccades made during the  
524 eccentric shooting condition do not contribute to the perception of object positions in the  
525 peripheral field of vision .. Hennig & Wörgötter (2003) through a model of the vertebrate retinal  
526 response to resting and moving eye suggested that eye movements in the range of microsaccade  
527 can contribute to peripheral acuity by reducing the effects of neural undersampling induced  
528 aliasing. Chen, Ignashchenkova, Thier, & Hafed (2015) showed a neural response gain  
529 enhancement for peripheral locations in superior colliculus and frontal eye field prior to the  
530 occurrence of microsaccades. Although these studies suggest that microsaccades might enhance  
531 visual processing at peripheral locations, there is no strong evidence to believe that subjects in  
532 our task could be using it to their advantage. We believe that microsaccades occurring during the  
533 eccentric viewing condition could just be spontaneous events, or indicators of sustained covert  
534 attention, or a mixture of both. In any case, enhancements in peripheral visual processing afforded  
535 by microsaccades, if any, would be very low compared to their contribution in the fine visual  
536 discrimination at the fovea.

537         Finally, we emphasize the developments made in the study of microsaccade's role or the  
538 lack of it in various task scenarios. Initially the volitional control of microsaccade was suggestive  
539 of its role in oculomotor strategies (Steinman, Cunitz, Timberlake, & Herman, 1967; Winterson &  
540 Collewun, 1976; Steinman, Haddad, Skavenski, & Wyman, 1973) but Kowler & Steinman (1979)  
541 denied its role in cognitive tasks like counting. Most of the later studies focused on microsaccadic  
542 response to low level processes like transient visual display changes or exogenous attention shifts  
543 (Hafed & Clark, 2002; Engbert & Kliegl, 2003a). Recent studies have tried to expand the role of  
544 microsaccades in more complex tasks that require higher level functions. Betta & Turatto (2006)  
545 showed that microsaccade rate is linked to manual response preparation and can be a measure  
546 of readiness. Valsecchi, Betta, & Turatto (2007) showed that the characteristic microsaccade rate  
547 signature is temporally expanded in a visual odd ball task and the effect is more pronounced when  
548 the oddball is task relevant. Hafed et al. (2011) showed through a monkey study that  
549 microsaccades are aligned to the axis of sustained covert attention and might be used by the  
550 visual and oculomotor system as part of a sophisticated fixation strategy. Microsaccade studies  
551 have also expanded to the field of object categorization (Craddock, Oppermann, Müller, &  
552 Martinovic, 2017) , overt attentional selection (Meyberg, Sinn, Engbert, & Sommer, 2017),  
553 perceived compression of time (Yu et al., 2017), working memory (Dalmaso, Castelli, Scatturin,  
554 & Galfano, 2017), spatiotemporal information processing (Boi, Poletti, Victor, & Rucci, 2017),  
555 reading (Bowers & Poletti, 2017; Yablonski, Polat, Bonnef, & Ben-Shachar, 2017), idea

556 generation (Walcher, Körner, & Benedek, 2017) and music absorption (Lange, Zweck, & Sinn,  
557 2017). In the light of these recent studies, our current study adds to the evidence that  
558 microsaccade characteristics not only reflect low level processing, but they are also modulated  
559 during tasks involving higher cognitive processing.

560

## 561 **CONCLUSION**

562 Microsaccades are suppressed during the execution of fine acuity tasks like shooting even when  
563 they do not contribute in shifting gaze over task relevant objects. Such suppression might be  
564 reflective of the cognitive processes involved in such tasks like perceptual decision making and  
565 response preparation.

566

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