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Post-saccadic changes disrupt attended pre-saccadic object memory

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25 **Abstract (366 words, is that OK? No words limit?)**

26 Trans-saccadic memory is involved in keeping track of objects' locations and features across
27 saccadic eye movements. Pre-saccadic information is remembered across a saccade and compared
28 with post-saccadic information. Trans-saccadic memory has been shown to have limited resources
29 and attention plays a role in the selection of objects and features for trans-saccadic memory. In
30 support, it has been previously shown that the recognition of distinct post-saccadic objects in the
31 visual scene is impaired when pre-saccadic objects are relevant and thus already encoded in memory
32 (Poth, et al., 2015). Here we investigated the inverse, i.e., how the memory of pre-saccadic objects is
33 affected by various abrupt but irrelevant changes in the post-saccadic visual scene. It is known that
34 attention is directed to the upcoming saccade goal location, prioritizing it for allocation to memory,
35 a phenomenon called pre-saccadic attentional facilitation. We therefore varied the attention to the
36 relevant pre-saccadic object by having participants either make a saccade to it or elsewhere, and
37 observed that pre-saccadic attentional facilitation also affected the saliency of post-saccadic changes,
38 i.e. their ability to disrupt trans-saccadic memory of pre-saccadic object.

39 Participants were asked to identify a briefly flashed symbol (d, b, p or q, randomly selected, among 2
40 and 5 distracters), at one of six placeholders (figures "8") arranged in circle around fixation while
41 planning a saccade to one of them. They reported the identity of the flashed symbol after the
42 saccade. We changed the post-saccadic scene in two ways. In experiment one, we removed different
43 parts (entire scene, only the placeholder where the pre-saccadic symbol was presented, or all other
44 placeholders except this one). We observed reduced identification performance when only the
45 saccade-target placeholder disappeared after the saccade. In experiment two, we changed one
46 placeholder location (inward/outward shift or rotation re. saccade vector) after the saccade and
47 observed that identification performance decreased with increased shift/rotation of the saccade-
48 target placeholder.

49 We conclude that pre-saccadic memory is disrupted by abrupt attention-grabbing post-saccadic
50 changes of visual scene, particularly when these changes involve the object prioritized by being the
51 goal of a saccade. These findings support the notion that limited trans-saccadic memory resources
52 are disrupted when object correspondence at saccadic goal is broken through removal or location
53 change.

54 Keywords: pre-saccadic attentional facilitation, trans-saccadic memory, eye movements

55 **Introduction**

56 Trans-saccadic memory is involved in keeping track of an object's location and its features across
57 saccadic eye movements (Cavanagh et al., 2010; Mathôt & Theeuwes, 2011; Rolfs, 2015; Rolfs et al.,
58 2011; Poth & Schneider, 2018; Jeyachandra et al., 2018; Prime et al., 2007), allowing an accurate
59 comparison of pre- and post- saccadic information about the object (Ganmor et al., 2015; Hayhoe et
60 al., 1991; Mathôt & Theeuwes, 2011; Vaziri et al., 2006; Wolf & Schütz, 2015).

61 There is consensus that trans-saccadic memory relies on visual working memory and involves
62 attention (Frost et al., 2019; Prime et al., 2007; Irwin, 1992; Irwin, 1996; Irwin & Andrews, 1996;
63 David & Bays, 2019; Mathot & Theeuwes; Melcher, 2009; Poth, Herwig & Schneider, 2015; Poth &
64 Schneider, 2016, 2018; Stewart & Schutz, 2017; 2018). Researchers have shown similar limited
65 memory capacity for trans-saccadic and visual working memory (Irwin, 1992; Irwin, 1996; Irwin &
66 Andrews, 1996; Prime et al., 2007). Further, it has been proposed that attention may be the
67 mechanism by which an object is allocated to trans-saccadic memory (Mathot & Theeuwes, 2011),
68 supported by the finding that cued objects were better remembered across saccades compared to
69 un-cued objects (Prime et al., 2007; Melcher, 2009). Similarly, removing attention impaired the
70 integration of peripheral and foveal object information across saccades, likely due to a disruption in
71 allocation to trans-saccadic memory (Stewart & Schutz, 2018). A recent study by Poth & Schneider
72 (2018) also showed that attended objects are prioritized for access to memory at the expense of
73 other objects when object correspondence is broken. Specifically, attended pre-saccadic objects
74 impaired recognition of different post-saccadic objects, with the number of pre-saccadic attended
75 objects directly related to the level of post-saccadic recognition impairment. In a previous study
76 (Poth et al., 2015), they suggested that breaking object correspondence between the pre- and post-
77 saccadic objects taxes trans-saccadic memory resources. Besides task-based object relevance, it has
78 been suggested that the saccade goal object also receives an attentional benefit and is therefore
79 prioritized to be stored in trans-saccadic memory (Mathot & Theeuwes, 2011; Rolfs, 2015; Rolfs &
80 Ohl, 2014; Irwin, 1992; Irwin, 1996; Irwin & Andrews, 1996). Indeed, attention is known to be
81 spontaneously allocated toward the object located at the saccadic goal before it is executed, a
82 phenomenon called pre-saccadic facilitation (Deubel, 2008; Deubel & Schneider, 1996; Hoffman &
83 Subramaniam, 1995; Khan et al., 2010, 2015; Kowler et al., 1995; Castet et al., 2006; Deubel &

84 Schneider, 1996; Hoffman & Subramaniam, 1995; Kowler et al., 1995; Mikula et al., 2018). In
85 summary, both relevant and saccade goal objects are prioritized for allocation into limited trans-
86 saccadic memory resources.

87 While previous studies have shown that pre-saccadic memorized objects impair recognition of post-
88 saccadic objects(), the inverse remains unknown, that is how attended post-saccadic objects
89 influence the memory of pre-saccadic objects. Besides relevance, attention can also be grabbed by
90 abrupt onsets/offsets, or displacements in the visual scene, typically known as exogenous attention
91 (references). Do such post-saccadic objects' changes impair the memory of pre-saccadic objects?
92 This finding would support the idea of a limited resource trans-saccadic memory with attention
93 influencing both the encoding of information as well as its retention.

94 We investigated how the memory of relevant pre-saccadic object features was affected by abrupt
95 post-saccadic changes in the visual scene. In experiment one, we removed parts of the visual scene
96 post-saccadically in different ways. In experiment two, we changed one placeholder location post-
97 saccadically in different ways. Participants had to identify and remember a symbol presented pre-
98 saccadically at one of six placeholders arranged circularly around fixation. At the same time, they
99 made a saccade to one of the six placeholders as indicated by a central cue. The attention directed
100 toward the relevant pre-saccadic object was thus varied by having participants either make a saccade
101 to it (valid trials) or make a saccade elsewhere (invalid trials). The attention was also directed post-
102 saccadically toward the saccadic goal location, thereby increasing the saliency of post-saccadic
103 changes breaking object correspondence at this specific location.

104

105 *Experiment 1*

106 **Methods**

107 We tested how changes in the visual scene after the saccade influenced discrimination of the target
108 before the saccade. There were 4 different conditions, 1) baseline condition with no change after
109 the saccade, 2) OneOff condition, in which only one placeholder disappeared, either at the saccade
110 goal location or at a distractor location, 3) AllOff condition, in which all placeholders disappeared
111 after the saccade, 4) OneOn condition in which all but the placeholder at the saccade goal or at a
112 distractor location disappeared.

113 Participants

114 Ten participants took part in the experiment (3 male, $M = 22.9$ years, $SD = 6.1$ years). Authors AL,
115 AK and JG were participants in the experiment. All participants had normal or corrected-to-normal
116 vision (glasses, contact lenses). They gave their consent in writing and were reimbursed for their
117 time. The study was approved by the Health Research Ethics Board (CERES) of the University of
118 Montreal, QC, Canada. We calculated a sample size of 8 using G*Power (Faul, Erdfelder, Lang &
119 Buchner, 2007), with an effect size of 0.4, with 1 group and 8 measurements using a repeated-
120 measures within group ANOVA. The effect size was calculated from a previous similar study
121 (Mikula et al., 2018).

122 Apparatus and Procedure

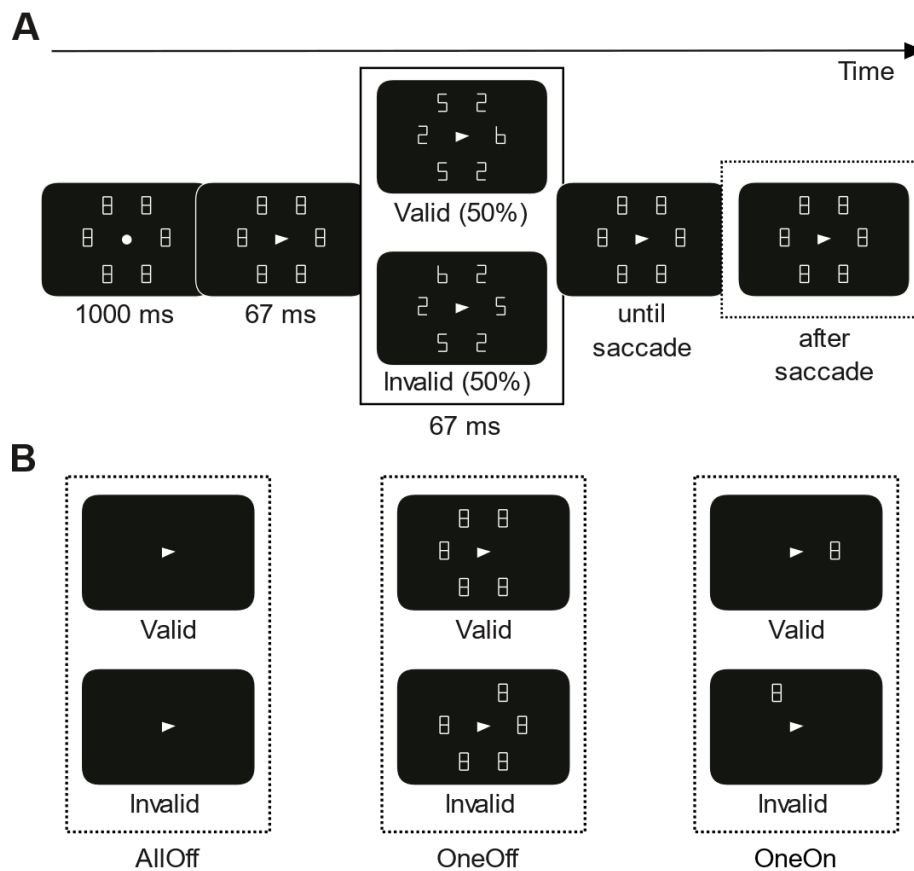
123 The experiment took place in a semi-dark room. Participants sat in front of an LCD screen
124 (VIEWPixx, VPixx Technologies, 53x30cm (22.5 inch display size), 1920x1200 pixels, 60 Hz refresh
125 rate, 34 cm eye-screen distance) with their heads stabilized by using head and chin rests. The height
126 of the support and chair were adjusted to center their eyes on the screen. The participants' right eye
127 movements were recorded by the Eyelink-1000-plus recording system (SR Research, Mississauga,
128 ON, Canada) at a frequency of 1000 Hz. Participants responded on a button box (RESPONSEPixx,
129 VPixx Technologies). The eye tracker was calibrated and validate using a 9-point calibration
130 sequence at the beginning of each block of 96 trials as described below.

131 Each condition was a variant of a dual saccade execution task and a four-alternative forced choice
132 discrimination task (Khan et al., 2010, 2015; Mikula et al., 2018). This paradigm has been modified
133 from previous studies (e.g. Schneider & Deubel, 1995) and has been robustly shown to provide a
134 measure of the allocation (quality and location) of pre-saccadic attention.

135 In the baseline condition (Figure 1A), a red fixation dot (0.5° diameter) first appeared at the center
136 of a black screen, surrounded by six red figure 8 placeholders (dimensions of $1.2^\circ \times 0.7^\circ$, shown in
137 white in figure 1) arranged in a circular layout (5.8° of eccentricity). After 1000 ms, the fixation dot
138 was replaced by an arrow ($1.0^\circ \times 0.7^\circ$) pointing toward one of the placeholders at random. The
139 participants were asked to make a saccade as quickly as possible toward the designated placeholder.
140 66.67 ms after the arrow's apparition, each placeholder's identity changed (for a short period of
141 66.67 ms). One of the figure 8's changed to one of 4 symbols (either d, b, p or q, randomly selected),
142 named the discrimination symbol (DS). The five remaining figures changed into non-pertinent

143 symbols (either 2 or 5). In 50% of the trials, the DS appeared at the placeholder designated by the
 144 arrow (valid position). In the other 50%, the DS appeared randomly among the five other
 145 placeholder locations (invalid position). The DS and non-pertinent symbols remained on for
 146 66.67ms before changing back to their previous identities, figure 8s. After making their saccade,
 147 participants were asked to identify the DS, regardless of its position, with a button box (forced
 148 choice). On the box, four buttons were identified as the possible answers. Each button was marked
 149 with a specific symbol (d, b, p or q). The mapping of symbol to button was the same for every
 150 participant and every block. Participants had to respond by choosing one of the 4 buttons for every
 151 trial (forced choice); they were asked to respond even if they weren't able to identify the DS and
 152 were asked to guess in that case. Pressing one of the buttons triggered the next trial. There was no
 153 time limit to answer and no feedback on participants' performance was provided. A block of trials
 154 consisted of 96 trials.

155 **Figure 1.**



156

157

158 Figure 1. *Experimental tasks*. (A) Baseline dual-task paradigm. Participants fixated a central dot
159 surrounded by six placeholders. The fixation dot was changed into an arrow for 67 milliseconds and
160 participants made a saccade to the placeholder designated by the arrow. Then, the DS appeared
161 either at the saccadic goal (valid) or at another placeholder (invalid). Remaining placeholders
162 changed into other symbols. 67 milliseconds after, all placeholders changed back to their previous
163 identities and remained until the end of the trial. (B) AllOff condition. After the saccade, all
164 placeholders disappeared until the end of the trial. (C) OneOff condition. After the saccade, only the
165 DS disappeared while other placeholders remained until the end of the trial. (D) OneOn condition.
166 After the saccade, only the DS remained while other placeholders disappeared until the end of the
167 trial.

168 Apart from the baseline condition, other conditions comprised post-saccadic changes triggered
169 when the participant's eye was detected outside a zone of 3.7° of diameter around the fixation point
170 (1.85° away from the fixation in any direction), plus an additional 50 ms to account for saccade
171 duration. Thus, changes occurred after the eye landed.

172 In the OneOff condition, the placeholder where the DS was presented disappeared (for both valid
173 and invalid positions) until the end of the trial (Figure 1C). All other symbols remained visible. Note
174 that in the valid trials, this is the saccade goal location. In invalid trials, this is a distractor placeholder
175 location.

176 In the AllOff condition, all placeholders disappeared until the end of the trial. Only the arrow
177 remained (Figure 1B).

178 In the OneOn condition, only the DS placeholder remained visible (in both valid and invalid
179 positions), whereas all other placeholders disappeared until the end of the trial (Figure 1D).

180 Before they could begin the experiment, participants performed at least three practice blocks (up to
181 a maximum of nine) in the baseline condition to ensure that they could perform the task correctly.
182 When they obtained at least 60% correct answers in the valid DS position, they could begin the
183 experiment. They then performed one block each of the different conditions in random order.

184 Data Analysis

185 We collected 3,840 trials in total, with 960 trials for each condition. Saccade onsets and offsets were
186 automatically detected using an algorithm with a velocity criterion to $30^\circ/\text{s}$, above which the
187 saccade was detected. They were subsequently verified visually.

188 We normalized eye positions in each block by adjusting them by how much the mean saccade start
189 position deviated from fixation point. This was to account for any errors in the calibration process;

190 we observed that while the pattern and distributions of eye positions were precise, there sometimes
191 tended to be an overall shift in positions, e.g. within a block, starting eye positions (when the
192 participant were looking at the fixation dot) were shifted up relative to the centre of the screen
193 where the fixation dot was located. We therefore shifted all positions across the block by the mean
194 shift at the start position.

195 Trials were removed from analysis according to the following criteria: 1) the camera lost the position
196 of the eye; 2) the participant blinked between the appearance of the arrow and the disappearance of
197 the DS or 3) the participant made more than one saccade to the target, 4) the participant responded
198 10s after trial start or longer, 5) the participant's saccade latencies in response to the arrow onset
199 were shorter than 100ms and longer than 600ms, 6) trials in which the start position (when
200 participants were fixating at centre) was more than 1.5° away from the fixation dot, 7) trials during
201 which saccade offset occurred before DS offset, ensuring that the DS was never viewed foveally, 6)
202 saccade amplitude was less than 3.8° or more than 7.8° (saccade target being at 5.8°) and 7) saccade
203 direction was outside 10° of the center of the saccade target placeholder. The latter two was due to
204 previous studies associating discrimination performance to saccade landing positions to some degree
205 (Mikula et al., 2018; Wick et al., 2016). In total, there remained 3,031 (78.9%) trials. Details about
206 the number of excluded trials can be found in supplemental table 1.

207 Discrimination performance was calculated with correct response rates (the DS was correctly
208 identified) and the tests were separated into two categories for each condition: (i) valid position – the
209 DS appeared at the saccade goal location designated by the arrow, and (ii) invalid position - the DS
210 appeared elsewhere.

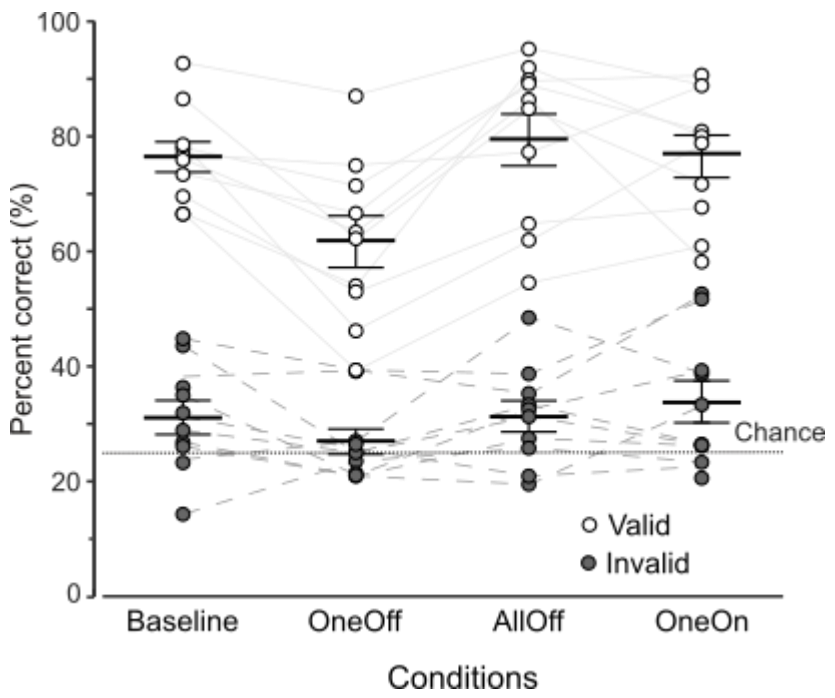
211 We performed repeated-measures ANOVAs and Holm-Bonferroni family-wise corrected paired t-
212 tests to compare performance. ANOVA degrees of freedom reported were Greenhouse-Geiser
213 corrected if Mauchly's test of sphericity was significant. We estimated the extent to which
214 performance differences could be explained by our manipulations with effect sizes, reporting partial
215 eta squared (η^2_p) s for ANOVAs (Lakens, 2013). We also reported Bayes factors for all ANOVAs
216 (BF_M) and t-tests (BF_{10}) performed.

217 **Results**

218 *Baseline performance*

219 We confirmed that pre-saccadic attentional facilitation occurred by analyzing participants’
 220 performance in the baseline condition, where the visual scene did not change after the saccade.
 221 Figure 2 (leftmost data) depicts mean performance for the valid and invalid positions for the
 222 baseline condition. Individual mean performance is also shown (filled dots). Performance for the
 223 valid position was significantly higher than the invalid positions (one-way repeated measures
 224 ANOVA, $F(1,9) = 144, p < .001, \eta^2_p = 0.941, BF > 100$). In addition, while performance was
 225 significantly different from chance (25%) in the valid position (76.6% correct, $t(9) = 19.5, p < .001$), it
 226 was not for the invalid positions (31.3%, $t(9) = 2.1, p = .064$). These findings are very similar to our
 227 and others’ findings demonstrating that attention is shifted to the goal of the saccade and not
 228 elsewhere when planning a saccade (Castet et al., 2006; Deubel & Schneider, 1996; Hoffman &
 229 Subramaniam, 1995; Khan et al., 2015; Mikula et al., 2018).

230 **Figure 2.**



231

232

233 Figure 2. *Pre-saccadic discrimination performance across conditions in valid and invalid positions.* Performance
 234 for individual participants is shown as white circles connected by light gray solid lines for the valid
 235 position and as grey circles connected by gray dashed lines for the invalid position. Mean correct
 236 discrimination rate in percentage (%) is shown by the wider black horizontal bars. Lighter grey bars
 237 represent standard error of the mean (s.e.m.). Chance is depicted by the dotted line at 25% of
 238 correct discrimination.

239 *Experimental conditions*

240 Figure 2 depicts performance for all 4 conditions (Baseline, OneOff, AllOff, OneOn) in valid and
241 invalid positions. A two-way repeated measures ANOVA revealed significant main effects for both
242 Condition ($F(3,27)=7.4$, $p<.001$, $\eta^2_p = 0.451$, $BF_M>100$) and Position ($F(1,9)=165$, $p<.001$, $\eta^2_p =$
243 0.948 , $BF_M=4.85$). There was also a significant interaction effect ($F(3,27)=4.8$, $p=.008$, $\eta^2_p = 0.347$,
244 $BF_M=3.18$). Comparing across the valid position, post-hoc Bonferroni-Holm corrected paired t-tests
245 confirmed significantly lower performance for the OneOff condition ($M= 61.9\%$, $SD = 14.2\%$)
246 compared to all other conditions (baseline - $M =76.6\%$, $SD = 8.3\%$, $t(9)=4.5$, $p=.001$, $BF_{10}=27$,
247 AllOff - $M= 79.6\%$, $SD= 14.2$, $t(9) = 5.7$, $p<.001$, $BF_{10}>100$, OneOn - $M= 76.7\%$, $SD= 11.6\%$, $t(9)$
248 $= 4.1$, $p=.003$, $BF_{10}=23$). Performance for the AllOff and the OneOn condition were not different
249 from the baseline condition ($p>0.05$, $BF_{10}=0.4$ and $BF_{10}=0.3$ respectively). Comparing across the
250 invalid condition, post-hoc comparisons revealed no differences between any of the conditions
251 ($p>0.05$, all $BF_{10}<1$, except for between the AllOff and the OneOn condition, where $BF_{10}=5.5$).

252 *Timing of placeholder change*

253 To test whether differences in timing of the placeholder change could explain the results, we
254 calculated the time between the change in the placeholders and the time of saccade offset
255 (completion of the saccade). As mentioned earlier, post-saccadic changes were programmed to occur
256 when the eyes moved more than 1.85° in any direction outside of fixation plus 50 ms. Saccade
257 durations were on average 40.3 ms (SD across participants = 4.58 ms, average within participant SD
258 $=5.37$ ms). The mean placeholder change was 39.7ms (SD across participants = 4.58 ms, average
259 within participant $SD =5.37$ ms) after the saccade was completed; a repeated-measures ANOVA
260 with condition and position as factors revealed no main effect for Condition (OneOff, AllOff and
261 OneOn) or Position nor a significant interaction effect (all $p>0.05$, $BF_M<1.2$). Thus, we conclude
262 that differences across conditions in the timing of the placeholder change cannot explain the results.

263 *Saccade latencies*

264 The mean saccade latencies were similar across the 4 conditions (Baseline – $M= 243$ ms, SD across
265 participants = 22ms, average within participant $SD =27$ ms; OneOff – $M= 239$ ms, SD across
266 participants = 19ms, average within participant $SD =25$ ms; AllOff – $M= 242$ ms, SD across
267 participants = 27ms, average within participant $SD =30$ ms; OneOn – $M= 249$ ms, SD across
268 participants = 21ms, average within participant $SD =28$ ms). We confirmed that there were no

269 differences in saccade latencies across condition or position (valid vs invalid) nor any interaction
270 effects (all $p > 0.05$, $BF_M < 0.5$).

271

272 **Experiment 1 summary**

273 First in the baseline condition, we showed that performance was better when the DS was flashed at
274 the saccade goal location than at another placeholder location. This confirms that attention was
275 shifted to the goal of the saccade pre-saccadically which lead to a better trans-saccadic encoding
276 and/or retention of the DS when it also represents the saccade goal (valid position).

277 When the DS was presented at invalid position, where identification performance at baseline was at
278 floor (chance level), the decrease in performance when only the DS location disappeared (invalid
279 OneOff) did not reach significance, performance was also unaffected when all but the DS location
280 disappeared (invalid OneOn) and when all the placeholders disappeared (AllOff). For the valid
281 position (when the DS also represented the saccade goal location), we observed a decrease in
282 performance when there was a post-saccadic change only at the saccade goal location (valid OneOff
283 condition), there was no change from baseline when all the placeholders disappeared (AllOff) and
284 when all but the saccade goal location placeholder disappeared (valid OneOn).

285 Considering these results, we speculate that performance decreased when there was a change in the
286 visual scene breaking object correspondence only the saccade goal location. In contrast, removing
287 all the placeholders in the AllOff condition did not affect performance, thus the memory of the pre-
288 saccadic object was likely not disrupted by a global change of the post-saccadic visual scene. Also,
289 abrupt offsets of the visual scene not concerning the saccade goal, such as in the OneOn condition,
290 did not affect performance, suggesting that post-saccadic changes occurring outside the focus of
291 attention did not seem to disrupt memory of the pre-saccadic object. Instead memory disruption
292 appeared to depend on a specific removal involving the most attended object between the pre- and
293 post-saccadic views relative to a constant scene.

294 In the next experiment, we shifted the target instead of causing it to disappear, thus changing
295 location in different ways rather than removing the object. Along the same logic as experiment 1, a
296 shifted rather than removed placeholder at the saccade goal location relative to an otherwise

297 constant visual scene should also impact performance, because it also induces a mismatch between
298 the pre- and post-saccadic representations of the most-attended object only.

299 *Experiment 2*

300 **Methods**

301 Here, we tested how changing the location of the placeholder after the saccade influenced pre-
302 saccadic discrimination performance. We tested 2 conditions, 1) the saccade goal or distractor
303 placeholder shifted inwards or outwards relative to fixation and 2) the saccade goal or distractor
304 placeholder rotated (Figure 3A).

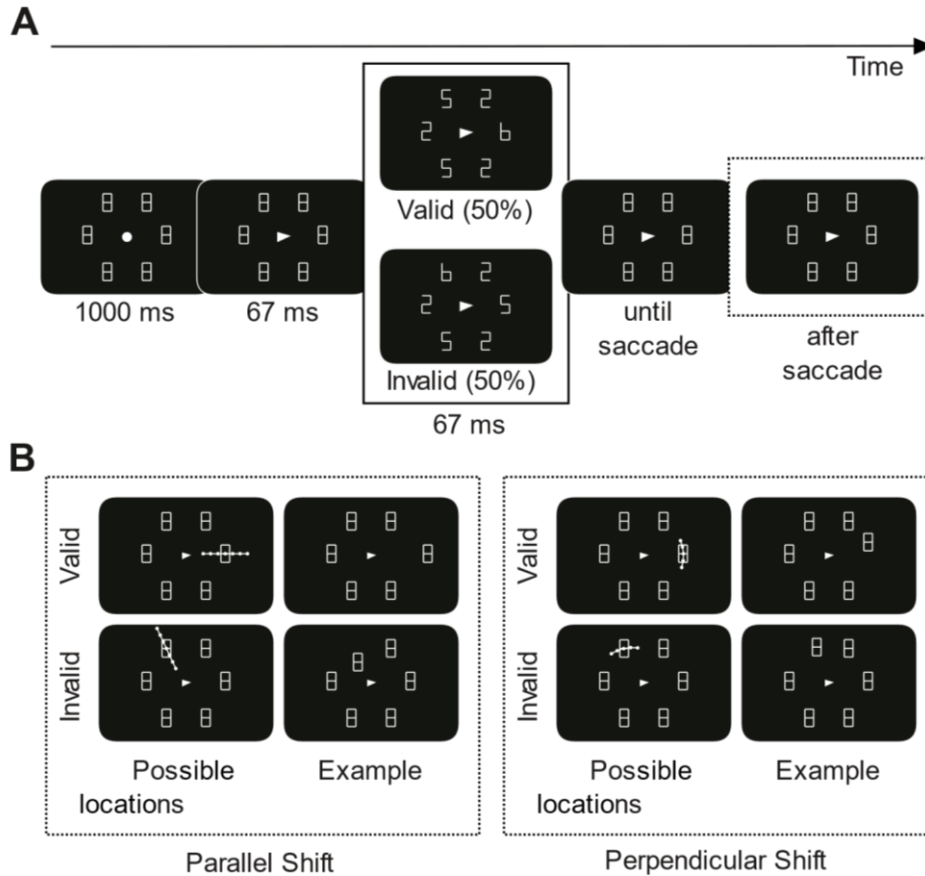
305 Participants

306 Nineteen participants (7 male, $M = 23.3$ years, $SD = 5$ years) were recruited for the shift condition.
307 Twelve participants took part in the rotate condition (4 male, $M = 24.5$ years, $SD = 5.8$ years),
308 eleven of which were the same as in the shift condition. All participants, apart from authors AL, JG
309 and AK, who participated in both experiments, were naïve to the goals of the experiments. All had
310 normal or corrected to normal vision. They gave their written consent and were reimbursed for their
311 participation. The experiment was approved by the Health Research Ethics Board (CERES) of the
312 University of Montreal, QC, Canada. We calculated a sample size of 11 using G*Power (Faul,
313 Erdfelder, Lang & Buchner, 2007), with an effect size of 0.4, with one group and 7 measurements
314 using a repeated-measures within group ANOVA. The effect size was calculated from a previous
315 similar study (Mikula et al., 2018).

316 Apparatus and Procedure

317 We used the same setup as experiment 1. For all conditions, 50% of the trials, the DS was located at
318 the saccadic target (valid position) and for the remaining 50%, it was located elsewhere (invalid
319 position). Both the shift and rotate conditions comprised post-saccadic changes, triggered when the
320 participant's eye was detected outside a zone of 2.9° of diameter around the fixation point, with no
321 additional delays (Figure 3A). Thus, changes occurred during the saccade before the eye landed.

322 **Figure 3.**



323

324

325 Figure 3. *Experimental dual-task paradigm.* (A) Baseline condition. Participants fixated a central dot
 326 surrounded by six placeholders. The dot was changed into an arrow for 67 milliseconds and
 327 participants made a saccade to the placeholder designated by the arrow. Then, the DS appeared
 328 either at the saccadic goal (valid) or at another placeholder (invalid). Other placeholders changed
 329 into other symbols. 67 milliseconds after, all placeholders changed back to their previous identities
 330 and remained until the end of the trial. (B) Condition of location shift along the visual vector
 331 direction (Parallel Shift) is displayed on the left panel. After the saccade, the DS was shifted at either
 332 0° (no shift), 1°, 2° or 3°, either inwards towards fixation or outwards. Rotated shift condition
 333 (Perpendicular Shift) is displayed on the right panel. After the saccade, the DS was shifted at either
 334 0° (no shift), 10° or 20° either clockwise or counter-clockwise.

335 In the parallel shift condition, upon the participants' saccade, the DS location shifted to one of 7
 336 locations, 3° inwards, 2° inwards, 1° inwards, 0° (no shift), 1° outwards, 2° outwards and 3°
 337 outwards. All other symbols remained at their original positions and this configuration did not
 338 change until the end of the trial. The 7 possible shifts were balanced across the block and trial order
 339 was randomized. The DS would shift regardless of its position, even when it was not at the saccadic
 340 goal location (invalid position).

341 In the perpendicular shift/rotate condition , the DS placeholder rotated 20° counter-clockwise, 10°
342 counter-clockwise, 0° (no shift), 10° clockwise and 20° clockwise upon the participants' saccade. All
343 other symbols remained at their original positions. The 5 possible rotations were balanced across the
344 block and trial order was randomized.

345 Participants first completed 1 to 6 practice blocks in the baseline condition until they obtained 60%
346 to 70% of correct answers in the valid position. They then completed 5 to 9 blocks (84 trials each)
347 for the parallel shift condition and 3 to 6 blocks (100 trials each) for the rotate condition in a
348 randomized order. In total, each participant completed 720 to 1256 trials. The number of trials
349 completed by each participant depended on the amount of their lost trials due to the absence of a
350 saccade or the presence of invalid saccades found in data analysis.

351 Data Analysis

352 We collected 10,500 trials for the shift condition and 4,496 trials for the rotate condition. Along the
353 lines of experiment 1, saccades were detected automatically with a velocity criterion of 30°/s of
354 velocity, then verified visually. Start and end positions were normalized to the mean saccade start
355 position for each block. We removed the trials in which 1) the camera lost eye position, 2)the
356 participant blinked 3) made more than one saccade to the target 4) responded more than 10 seconds
357 after trial start, 5) saccade latencies were shorter than 100ms or longer than 600 ms, 6) the
358 participant's initial eye fixation position was more than 1.5 cm away from central fixation point, 7)
359 saccade offset occurred before DS offset, 8) saccade amplitudes were smaller than 3° or greater than
360 8° and 9) saccade directions were outside of 20° of the center of the placeholder position. In
361 contrast to experiment 1 where we selected precise saccade trials, here we included a larger range of
362 saccade endpoints in order to test for the impact of saccade variability. There remained 8,828 trials
363 for the shift condition and 3,673 trials for the rotate condition. Details about the number of
364 excluded trials can be found in the supplemental tables 2 and 3.

365 Discrimination performance was calculated as in experiment 1. Repeated measures ANOVAs and
366 post-hoc Holm-Bonferroni corrected t-tests were conducted for all statistical analyses. ANOVA
367 degrees of freedom reported were Greenhouse-Geiser corrected if Mauchly's test of sphericity was
368 significant. We estimated the extent to which performance differences could be explained by our
369 manipulations with effect sizes, reporting partial eta squared (η^2_p) s for ANOVAs (Lakens, 2013).
370 We also reported Bayes factors for all ANOVAs (BF_M) and t-tests (BF_{10}) performed.

371 **Results**

372 We conducted two separate repeated-measures ANOVAs for parallel and perpendicular shifts and
373 for the valid and invalid positions.

374 *Performance as a function of DS placeholders parallel shifts*

375 In the invalid condition, the repeated-measures ANOVA showed no identification performance
376 difference between any shift conditions, $F(6, 108) = 1.42, p > 0.05, BF_M = 0.2$ (range: 30.2% to 36.2%,
377 all significantly different from chance of 25% ($p < 0.05$) except for -3° and -2° shifts ($p > 0.05$)).

378 Figure 4A shows discrimination performance for every DS parallel shifts (-3° to $+3^\circ$) for the valid
379 condition. For valid positions, performance varied as a function of target shift, $F(4.2, 76.1) = 4.51,$
380 $p < 0.001, \eta_p^2 = 0.2, BF_M = 64.33$. We performed Holm-Bonferroni corrected post-hoc t -tests to test
381 for differences from the baseline (0°) condition; they revealed differences between the highest
382 performance observed for 0° shift (baseline position; $M = 74.1\%$, $SD = 15.9$) and performance
383 observed for almost every other shifts of location (with -3° inwards, $M = 64.4\%$, $SD = 19.3\%$: $t(18)$
384 $= 2.74, p < 0.05, BF_{10} = 4.03$; with $+1^\circ$ outwards, $M = 66.3\%$, $SD = 19.4\%$: $t(18) = 2.85, p < 0.05, BF_{10} =$
385 4.96 ; with $+2^\circ$ outwards, $M = 64.4\%$, $SD = 17.9\%$: $t(18) = 2.96, p < 0.05, BF_{10} = 6.02$; with $+3^\circ$
386 outwards, $M = 62.4\%$, $SD = 19.5\%$: $t(18) = 3.24, p < 0.05, BF_{10} = 10.11$, Holm-Bonferroni corrected),
387 except the -2° ($p > 0.05, BF_{10} = 1$) and -1° inward locations ($p > 0.05, BF_{10} = 0.26$). In sum, the best
388 performance was at 0° , which corresponded to baseline. Compared to this position, performance
389 was impaired especially in the most inwards shift (-3°) and all outwards shifts ($+1^\circ, +2^\circ$ and $+3^\circ$).

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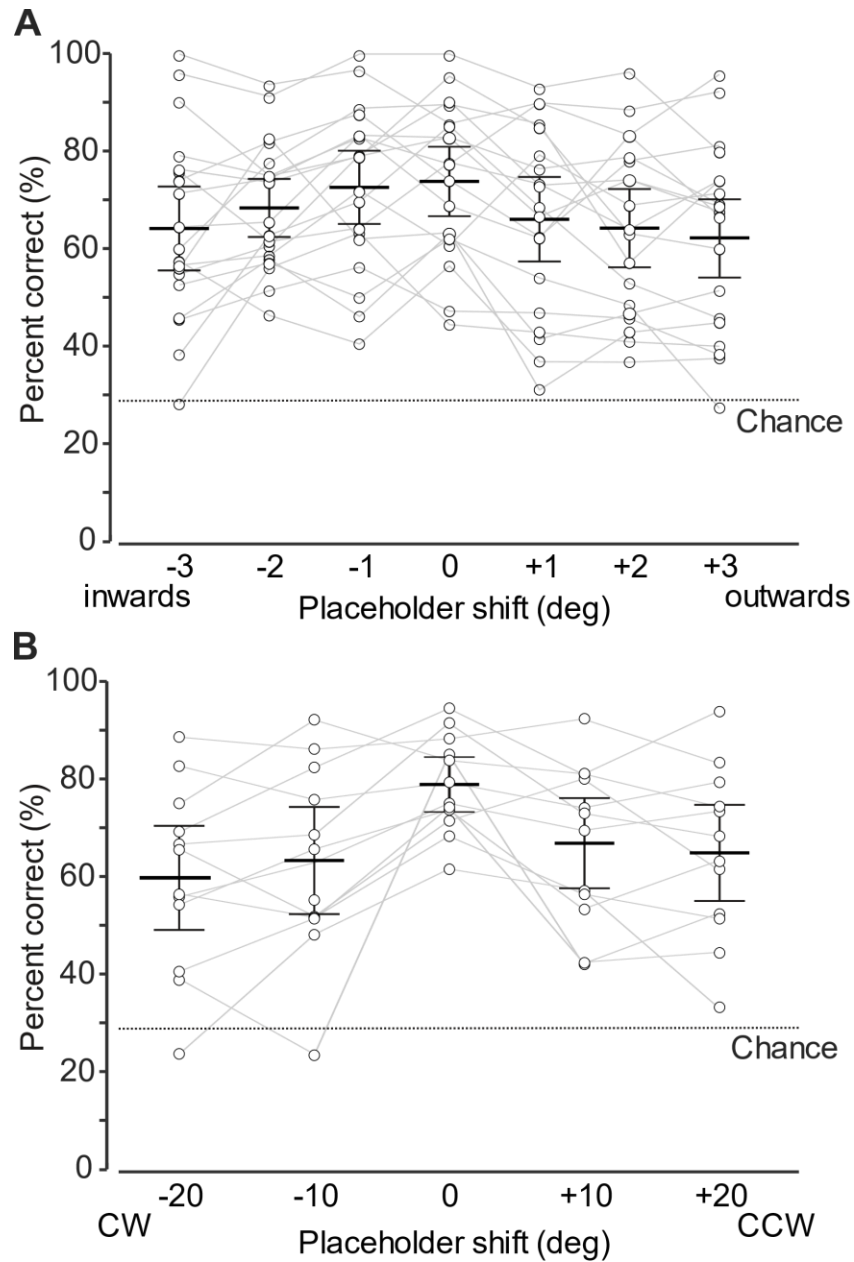
393

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396

397 **Figure 4.**



398

399 Figure 4. *Pre-saccadic discrimination performance across shift conditions in valid position.* Performance for
 400 individual participants is shown as white circles connected by solid gray lines. Mean correct
 401 discrimination rate in percentage (%) is shown by the wider black horizontal bars. Lighter grey bars
 402 represent standard error of the mean (s.e.m.). Chance is depicted by the dotted line at 25% of
 403 correct discrimination (A) Discrimination performances is shown for every parallel shift of the
 404 placeholder. (B) Discrimination performance is shown for every perpendicular shift of the
 405 placeholder.

406

407 *Performance as a function of rotated DS placeholders*

408 In this condition, the DS could rotate 10° or 20° clockwise or counter-clockwise from its initial
409 position (-20, -10, +10, +20), during the participants' saccade and in both valid and invalid positions.
410 As with the previous analysis, the repeated-measures ANOVA comparing DS placeholder rotations
411 in the invalid position showed no differences in performance for any rotation, $F(4, 44) = 0.65$,
412 $p > 0.05$, $BF_M = 0.19$ ((range: 31% to 36.4%, all significantly different from chance of 25% ($p < 0.05$))
413 except for -3° and -2° shifts ($p > 0.05$)).

414 Figure 4B shows discrimination performance for every DS rotated location in the valid condition.
415 The repeated-measures ANOVA for the valid condition found differences as a function of DS
416 placeholder rotation, $F(4, 44) = 7.54$, $p < 0.01$, $\eta_p^2 = 0.41$, $BF_M = 232$. We performed Holm-
417 Bonferroni corrected post-hoc t -tests to test for differences from the baseline (0°) condition; these
418 tests revealed decreased performances in rotations of -20° ($M = 61\%$, $SD = 18.8\%$; $t(11) = 4.22$,
419 $p < 0.05$, $BF_{10} = 34$), -10° ($M = 64.9\%$, $SD = 16.1\%$; $t(11) = 3.64$, $p < 0.05$, $BF_{10} = 6.31$), +10° ($M =$
420 66.6% , $SD = 15.8\%$; $t(11) = 2.83$, $p < 0.05$, $BF_{10} = 4$) and +20° ($M = 64.6\%$, $SD = 16.1$; $t(11) = 4.01$,
421 $p < 0.05$, $BF_{10} = 24$), compared to no rotation baseline ($M = 77\%$, $SD = 9\%$). In sum, the best
422 performance was at 0° (baseline), while it was lower for all other placeholder rotations.

423 *Saccade landing positions*

424 We observed that the -1° and -2° shift were not different from baseline in the valid condition, while
425 the other shifts and all rotations were different and we wished to determine whether this was related
426 to saccade distribution patterns. In accordance with this observation, we performed some
427 exploratory analysis to determine whether the distribution of landing positions endpoints was linked
428 to discrimination performance.

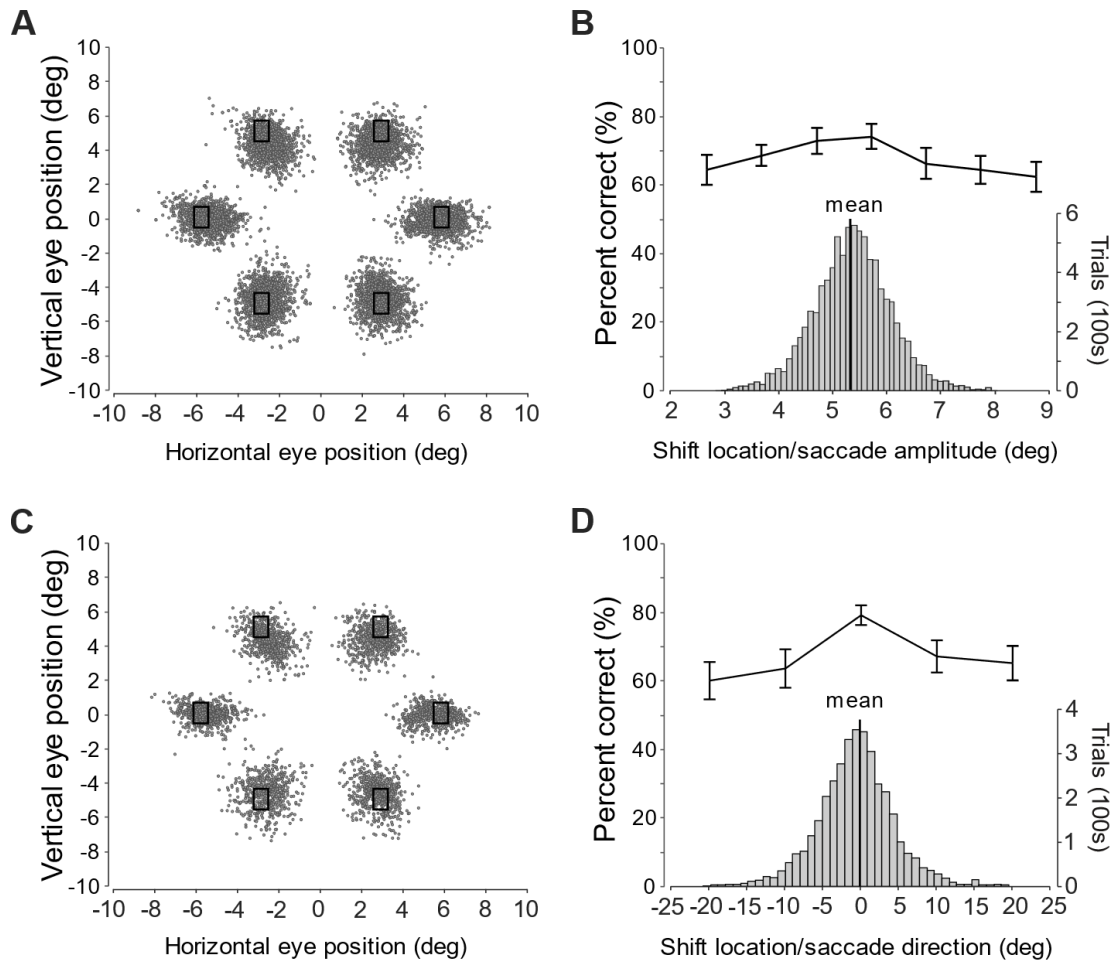
429 Figures 5A and C show saccade endpoints for all participants for the parallel shift and rotation
430 conditions respectively, for all trials. Previous studies have shown elliptical distributions with wider
431 distributions parallel compared to perpendicular to the saccade vector (van Opstal & van Gisbergen,
432 1989; Wexler & Collins, 2014). We observed a similar pattern for cardinal directions, while oblique
433 directions tended to have more circular distributions.

434 Figures 5B and D show the frequency counts of binned participants' saccade amplitudes compared
435 with average performance for the different placeholder parallel shifts, and of binned participants'
436 saccade directions compared with average performance for the different placeholder perpendicular
437 shifts, respectively, for the valid position. We did not look at the invalid position as there were no

438 differences in performance. As it can be seen, the distribution of saccade amplitudes and directions
439 seems to be linked to participants' performance; performance is high at the landing positions of
440 most saccades and lower where fewer saccades landed.

441

442 **Figure 5.**



443

444

445 Figure 5. *Saccade endpoint distribution and its relation to performance across parallel shift and rotate conditions in*
446 *valid position.* (A) Saccade endpoint positions in the array are shown as grey dots for every trial in the
447 parallel shift condition. Placeholder locations are shown in black. (C) Saccade endpoint positions in
448 the array are shown for every trial in the perpendicular shift/rotate condition. (B) Mean correct
449 discrimination rate in percentage (%) is represented by the curve for each change in location inwards
450 or outwards. Smaller grey bars represent standard error of the mean (s.e.m.). Saccade amplitude

451 distribution is represented by the histogram. (D) Mean correct discrimination rate in percentage (%)
452 is represented by the curve for each rotation clockwise or counter-clockwise. Saccade direction
453 distribution is represented by the histogram.

454

455 Most saccades had amplitudes varying between 4° and 7° for placeholders arranged in a circular
456 layout with 5.8° of eccentricity; the mean saccade amplitude was at 5.38° (SD = 0.3°), which was
457 significantly smaller than the placeholder distance ($t(18)=5.7$, $p<0.001$, $BF_{10}>100$). This is consistent
458 with many studies which show that participants tend to undershoot targets particularly for
459 centrifugal saccades (Gillen et al., 2013; Irving et al., 2006; Nuthmann et al., 2016). First, we
460 investigated participants' mean amplitudes to determine whether they undershot the pre-saccadic
461 placeholder location, consistent with good performance at the no shift, -1° and -2° placeholder
462 parallel shifts. We tested whether there was a correlation between the parallel shift at which a
463 participant had their best performance and their mean saccade amplitude. We did not find a
464 significant correlation ($p<0.05$). It should be noted that most participants (9 of them) had their best
465 performance at the no shift baseline position and that the range of mean saccade amplitudes across
466 participants was small. We also tested within each participant whether performance was different
467 when their saccade amplitudes were smaller compared to bigger. We performed a median split on
468 each participant's saccade amplitudes and then calculated performance at each DS parallel shift
469 separately for the trials with smaller amplitudes (M across participants = 4.88° vs. bigger amplitudes
470 (M across participants = 5.88°). We then compared performance using a repeated measures
471 ANOVA with median group (smaller vs. bigger saccades amplitudes) and shift (all 7 positions) as
472 factors. We found no significant main effect of group ($F(1,18)=2.5$, $p<0.05$, $BF_M=0.019$) nor a
473 significant interaction effect ($F(6,108)=1.4$, $p>0.05$, $Bf_M = 0.46$) as would be expected if there was a
474 different in performance depending on saccade amplitude.

475 Next, we tested whether participants with wider distributions of saccade endpoints would show
476 smaller decreases in performance for the biggest parallel shifts. We performed a median split of
477 distributions/variability, separating participants into those with narrower distributions vs. wider
478 distributions, i.e smaller vs. bigger standard deviations for landing position. We then compared the
479 two groups in terms of change in performance from baseline to the inward 3° shift and as well from
480 baseline to the outward 3° shift. We found no differences between the two groups ($p>0.05$, BF_{10}
481 <0.67 , narrow distribution group SD = 0.57° , 13.72% inwards decrease in performance and 5.3%
482 outwards; wide distribution group SD = 0.7° , 14.4% inwards and 8.6% outwards).

483 We performed the same analyses for the rotation condition. Mean relative saccade direction was at -
484 0.01° (SD = 0.75°), which was not significantly different from the placeholder direction (0° ,
485 $t(11)=0.05$, $p=0.9$, $BF_{10}=0.28$). We did not find a significant correlation ($p<0.05$) between the
486 rotation position of best performance and mean individual saccade direction; the best identification
487 performance was at the no rotation baseline position for 8 of our 12 participants and the range of
488 mean saccade directions across participants was small. We also tested within each participant
489 whether the pattern of performance across the different rotations was different when their saccade
490 directions were more clockwise compared to more counter-clockwise, using a median split analysis
491 (M across participants more clockwise = -0.57° , M across participants = 0.56° more counter-
492 clockwise) but found no significant effects ($p>0.05$, $BF_M<0.6$). Finally, we found that participants
493 with wider distributions in direction did not show differences in decreases in performance from
494 baseline to the outward-most rotations ($p>0.05$, $BF_{10}<0.5$).

495 In summary, we did not find a relationship between saccade distribution patterns and discrimination
496 performance in either the parallel shift or the rotation condition.

497

498 *Timing of the placeholder change*

499 We confirmed that there were no differences across location changes (collapsed across valid and
500 invalid positions) in the timing of the placeholder rotation relative to saccade offset for either the
501 shift condition ($p>0.05$, $BF_M=0.3$) or the rotation condition ($p>0.05$, $BF_M = 0$). Post-saccadic
502 changes in experiment 2 were programmed to occur when the eyes moved more than 1.85° in any
503 direction outside of fixation. Saccade durations for the shift condition were on average 40.8 ms (SD
504 across participants = 3.55 ms, average participant SD = 7.35ms). For the rotation condition, average
505 saccade duration was 41.8 ms (SD across participants = 5.14 ms, average participant SD = 7.23ms).
506 On average the placeholder changed positions 10.78ms (SD across participants = 3.68 ms, average
507 participant SD = 9.4ms) *before* saccade offset for the parallel shift condition and 11.75ms (SD across
508 participants = 4.32 ms, average participant SD = 8.84ms) *before* saccade offset for the rotation
509 condition.

510 *Saccade latencies*

511 The mean saccade latency for the parallel shift condition was 282ms (SD across participants = 53ms,
512 average within participant SD = 41ms) while for the rotate condition, it was 310ms (SD across
513 participants = 72ms, average within participant SD = 44ms). We confirmed that there were no
514 differences across (parallel or perpendicular) shifts or position (valid vs invalid) nor any interaction
515 effects for either the parallel shift condition (all $p > 0.05$, $BF_M < 0.5$) or the rotation condition (all
516 $p > 0.05$, $BF_M < 0.5$).

517 **Experiment 2 summary**

518 We observed that pre-saccadic discrimination performance decreased when the placeholder at the
519 saccade goal changed location during the saccade. Moreover, while there was a decrease in
520 performance for all rotations and most parallel shifts, notably performance did not decrease for the
521 two smallest inward shifts. In terms of saccade behaviour, the distribution of saccade landing
522 positions has been shown to play a role in the capacity to determine trans-saccadic object
523 correspondence, within the context of saccadic suppression of displacement (Van der Stigchel et al.,
524 2020; Wexler & Collins, 2014; but see Schut et al., 2018; Joosten & Collins, 2018). Even though
525 saccades are generally precise, a certain variability exists in their landing positions, from one person
526 to another. These abovementioned studies showed that when a saccade's target was shifted within
527 an elliptic region corresponding to the habitual distribution of saccade landing positions, its shift was
528 not perceived, and the object's stability was assumed. On the other hand, when the shift fell outside
529 this region, it was noticed by the observer. Thus, for the system to determine object
530 correspondence, it may take into consideration the distribution of landing positions, comprising
531 saccade accuracy, e.g. how much undershoot and saccade variability, e.g. how broad an area.

532 We therefore tested whether our participants' pattern of performance was related to saccade
533 endpoint distributions but did not find a significant relationship.

534

535 **General Discussion**

536 We tested how performance in a pre-saccadic discrimination task was influenced by post-saccadic
537 changes in the visual scene. We varied attention directed to the relevant pre-saccadic object
538 (discrimination symbol DS) by requiring a saccade either to that object or to another placeholder.
539 We manipulated the post-saccadic visual scene after the saccade in various ways (removals or

540 location changes) and found that pre-saccadic attentional facilitation not only affected the encoding
541 pre-saccadic symbol in memory but also the ability of the abrupt but nevertheless irrelevant post-
542 saccadic visual scene changes to disrupt the report of the pre-saccadic symbol. In other words, pre-
543 saccadic exclusive allocation of attention to the saccade goal rendered post-saccadic change
544 involving *exclusively* the saccade goal object more salient and disruptive of trans-saccadic memory,
545 probably because they break the correspondence of the most attended object between the pre- and
546 post-saccadic views relative to a constant scene.

547

548

549 In both experiments, in the baseline conditions with no change to the post-saccadic scene,
550 participants showed above chance discrimination when the symbol appeared pre-saccadically at the
551 saccade target goal location. The report of the symbol was after the saccade, showing that
552 participants were able to encode, remember and retrieve it well across the saccade. In contrast,
553 discrimination performance was at chance level when the symbol did not appear at the saccade goal
554 location, even though it was relevant to the task since participants were asked to discriminate the
555 symbol regardless of its position. This shows that preparing and executing a saccade toward another
556 location led to an exclusive allocation of attention to the saccade goal and prevented the selection of
557 the relevant symbol for trans-saccadic memory. This may have been because the task was too
558 difficult with remaining attentional resources needed to be distributed among 5 possible invalid
559 positions and chance level at 25% because of the four alternative choice discrimination (p,b,q,p).
560 However, even previous studies using simpler versions of this task (only 2 possible invalid positions
561 and two-alternative forced choice discrimination task) have shown chance level discrimination at the
562 invalid location. (Khan et al 2009). Of note, although this was not significant we did observe here a
563 performance decrease across most individuals in the OneOff invalid condition compared to the
564 invalid baseline condition, similar to the performance decrease in the OneOff valid condition
565 compared to the valid baseline condition (Figure 2). We speculate that if there had been above
566 chance discrimination in the invalid location (no floor effect), we may have similarly seen a
567 significant dip in discrimination performance. In theory post-saccadic changes at the object location
568 relevant to the task (discrimination symbol to report after the saccade), albeit a saccade is to be
569 executed elsewhere, should also disrupt trans-saccadic memory, although to a smaller degree as there
570 were fewer attentional resources allocated to this object. However, pre-saccadic attentional

571 facilitation is strongly directed at the saccade goal location at the expense of other, even relevant
572 locations. Facilitation by covert attention is not so exclusive (Khan et al 2015 EJN)

573 We thus observed above chance level discrimination performance and could study its modulation by
574 various irrelevant post-saccadic changes, only when the symbol appeared at the saccade goal location
575 (valid position). When we removed the entire scene after the saccade, there was no change to the
576 pattern of discrimination. Similarly, when we removed all placeholders but the saccade target
577 placeholder, there was no decrease in performance in the report of the symbol after the saccade.
578 However, when the saccade goal placeholder disappeared but all other placeholders remained, we
579 observed a decrease in discrimination performance. In a second experiment, we changed the
580 placeholder location (inward/outward shift or rotation re. saccade vector) and observed that
581 performance decreased with increased location change, but again only when the change occurred at
582 the saccade goal location relative to a constant visual scene. Taken together, these results imply that
583 the pre-saccadic memory of the symbol is disrupted due to a relative change in the visual scene
584 involving only the saccade goal placeholder, i.e. a disruption in object/scene correspondence. Since
585 performance was still well above chance (unlike when the DS appeared at a non saccade goal
586 location), we conclude attentional prioritizing into trans-saccadic memory still took place, but that
587 retention was disrupted because of this post-saccadic change.

588 We propose that abrupt post-saccadic changes occurring only at the saccade goal breaks pre- and
589 post-saccadic correspondence of the most attended object relative to a constant visual scene. This
590 specific post-saccadic change captured attention, leading to the encoding of this post-saccadic object
591 into memory, which consequently affected retention of pre-saccadic object information, due to
592 trans-saccadic memory resource limitation. It has been previously suggested that trans-saccadic
593 memory plays an important role in comparing information before and after a saccade (Aagten-
594 Murphy & Bays, 2019; Mathôt & Theeuwes, 2011; Van Eccelpoel et al., 2008). Trans-saccadic
595 memory has been considered to be based on visual working memory (Luck & Vogel, 1997), due to
596 the similarities in limited memory capacity as well as the timing duration of a few seconds (Irwin,
597 1992; Irwin, 1996; Irwin & Andrews, 1996; Luck & Vogel, 1997). Previous studies have shown
598 evidence for automatic attention leading to automatic encoding into visual working/trans-saccadic
599 memory (references), at the expense of the item already in memory, namely here memory of the pre-
600 saccadic symbol is disrupted, resulting in decreased discrimination performance. The observed

601 disruption of trans-saccadic memory due to post-saccadic changes therefore adds arguments for
602 limited resources in trans-saccadic memory (references to Poth studies here). If memory resources
603 were unlimited, we would expect no memory disruption, and thus no decreased discrimination
604 performance.

605 Our results also support the idea that pre-saccadic attentional facilitation is involved in selecting
606 information to be stored in trans-saccadic memory and compared after the saccade (Deubel et al.,
607 1998; Rolfs et al., 2011; Wolf & Schütz, 2015; Irwin & Robinson, 2015). It has been previously
608 suggested that pre-saccadic attention acts as a ‘gatekeeper’ for transsaccadic memory, or alternatively
609 as a predictive ‘pointer’ to remember and update objects’ identity and location across saccades
610 (Cavanagh et al., 2010; Rolfs et al., 2011; Van Eccelpoel et al., 2008; Prime et al., 2007; Melcher,
611 2009). We show evidence here that the saccade target grabs a large part of the attentional resources
612 before and also after the saccade execution, at the expense of other, even relevant objects.

613 We speculated that the determination of object correspondence for the saccade goal played a role in
614 the disruption of trans-saccadic memory, rather than an abrupt attention-grabbing change in saccade
615 placeholder. This was based on our observations of 1) no discrimination disruption in the AllOff
616 condition in the first experiment and 2) clear discrimination disruption when the saccade goal object
617 shifted of only 1° outwards in the second experiment. It has been suggested that breaking object
618 correspondence results in separate memory items of the pre- and post-saccadic objects, which
619 compete for limited trans-saccadic memory (Poth & Schneider, 2015). Numerous studies have
620 supported the relative importance of the post-saccadic object compared to the pre-saccadic one, for
621 visual stability (Deubel, Bridgeman & Schneider, 1998), i.e. the pre-saccadic information becomes
622 less relevant at the expense of the post-saccadic new object/scene, and so has fewer memory
623 resources. Further, the observation that discrimination performance decreased only when there was
624 a relative change at the saccade placeholder location, supports the idea that object correspondence
625 determination might be more related to the visual scene than just the saccade goal object itself. This
626 is consistent with a recent finding that other stimuli similar to the target may be perceptually
627 grouped and attended pre-saccadically (Shurygina, Pooresmaeili & Rolfs, 2019) and that factors such
628 as the relative positions of other objects in the scene (Deubel et al., 1998) also play a role in object
629 correspondence. We suggest that the removal of the entire visual scene (AllOff condition) in our
630 first experiment does not disrupt predictive mechanisms, likely because there is no comparison to
631 make between pre- and post-saccadic scenes. Specifically, since the entire scene changed and all

632 landmarks were gone, there was no comparison to make about the relative target position in the
633 scene. Note that such removal of the whole visual scene may be more predictable than a specific
634 change only at the saccade goal since it occurs as frequently as we blink.

635

636 Concerning the clear discrimination disruption when the saccade goal object shifted of only 1°
637 outwards in our second experiment, we speculated that the determination of object correspondence
638 might be related to saccadic variability. Indeed, previous studies on saccadic suppression of
639 displacement have shown that there is an assumption of object correspondence for pre- and post-
640 saccadic objects and that relatively large shifts are necessary to break this assumption (Bridgeman et
641 al., 1975; Mathôt & Theeuwes, 2011; Deubel et al., 1996). Within the context of saccadic
642 suppression of displacement, further studies have shown that the distribution of saccade landing
643 positions plays a role in the capacity to determine trans-saccadic object correspondence (Van der
644 Stigchel et al., 2020; Wexler & Collins, 2014; but see Schut et al., 2018; Joosten & Collins, 2018).
645 Along these lines, and given the distinct pattern of discrimination performance we observed for the
646 inward shifts of the saccade placeholder compared to the outwards shifts, we studied the correlation
647 between saccade landing positions and identification performance in our data. However, we did not
648 find any strong relationship between performance and saccade landing positions neither between
649 individuals nor between individual trials. This suggests that a general estimate of the noise in the eye
650 movement system may play a role in determining object correspondence, rather than the actual
651 saccade landing positions per se. Similarly, in a recent study investigating visual and proprioceptive
652 integration for reaching, we showed that the weighting of visual information did not depend on the
653 actual visual and proprioceptive variabilities of the dominant and non-dominant hands, but rather
654 on a learned constant estimate (Mikula et al., 2021). Thus it could be that there is some more general
655 variability estimate which is used by the system to determine object correspondence instead of one
656 based on saccade execution. This would explain some discord in previous related studies within the
657 context of saccadic suppression of displacement (Van der Stigchel et al., 2020; Wexler & Collins,
658 2014; Schut et al., 2018; Joosten & Collins, 2018) on whether trans-saccadic perception (object
659 correspondance) is related to saccade variability or not. .

660

661 *Timing of change*

662 The timing of the post-saccadic changes was different for the first and second experiments.
663 Specifically, the post saccadic changes occurred after the saccade landed at the placeholder for the
664 first experiment and occurred during the saccade for the second experiment. Previous studies on
665 trans-saccadic memory and object correspondence had post saccadic changes that occurred right at
666 the end of the saccade as well as long after the saccade landed, after 100ms (Poth & Schneider,
667 2015). They observed that object letter discrimination was worse when the postsaccadic changes
668 occurred long after the saccade landed. However, this cannot explain the results of our study.

669

670 *Not backward masking*

671 An alternative explanation for our results could have been backward masking. Specifically, the
672 appearance of a distractor after the target can result in decreased visibility of the target resulting in
673 decreased performance (Macknik & Livingstone, 1998). Typically, in backward masking, changes in
674 target identity leads to a decrease in performance. However, in all our conditions, the DS switches
675 back to a figure 8 , already masking it, only 140 ms after the cue indicating the saccade goal and thus
676 before occurrence of the saccade. In addition, object disappearance or change in location to our
677 knowledge is not known to cause backward masking. Furthermore, the timing of the changes is also
678 not consistent with backward masking. In an elegant study, Macknik and Livingstone (1998) showed
679 the peak backward masking occurs at about 100 ms between the termination of the target and
680 termination of the mask. In our paradigm, the DS was presented for 66.67ms then replaced by a
681 figure 8 placeholder, which remained visible for an average of 190ms (SD = 35ms) before its
682 disappearance.

683

684 **Conclusions**

685

686 In this pre-saccadic attentional facilitation study, we changed the visual scene in different ways after
687 the saccade. This manipulation was irrelevant to the pre-saccadic discrimination task. We found that
688 discrimination performance was nevertheless negatively affected by post-saccadic changes involving
689 specifically the saccade goal location. This confirms the notion of pre-saccadic attentional facilitation
690 being involved in visual stability across saccades, rather than being an independent phenomenon

691 whose role was limited to the pre-saccadic period. We explored the effects of various post-saccadic
692 object disappearance(s) on visual stability in experiment one and the spatial limits of pre- and post-
693 saccadic object location continuity in experiment two. Visual stability (or trans-saccadic memory) is
694 disrupted when object correspondence is broken between the pre- and post-saccadic objects (Poth
695 & Schneider, 2015; Poth et al. 2015). The present results provide insights into the criteria used by
696 the visual system to determine object correspondence across saccades.

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700 **References**

- 701 Aagten-Murphy, D., & Bays, P. M. (2019). Independent working memory resources for egocentric
702 and allocentric spatial information. *PLoS Computational Biology*, *15*(2).
703 <https://doi.org/10.1371/journal.pcbi.1006563>
- 704 Bridgeman, B., Hendry, D., & Stark, L. (1975). Failure to detect displacement of the visual world
705 during saccadic eye movements. *Vision Research*, *15*(6), 719–722. [https://doi.org/10.1016/0042-](https://doi.org/10.1016/0042-6989(75)90290-4)
706 [6989\(75\)90290-4](https://doi.org/10.1016/0042-6989(75)90290-4)
- 707 Castet, E., Jeanjean, S., Montagnini, A., Laugier, D., & Masson, G. S. (2006). Dynamics of
708 attentional deployment during saccadic programming. *Journal of Vision*, *6*(3), 196–212.
709 <https://doi.org/10.1167/6.3.2>
- 710 Cavanagh, P., Hunt, A. R., Afraz, A., & Rolfs, M. (2010). Visual stability based on remapping of
711 attention pointers. *Trends in Cognitive Sciences*, *14*(4), 147–153.
712 <https://doi.org/10.1016/j.tics.2010.01.007>
- 713 Deubel, H. (2008). The time course of presaccadic attention shifts. *Psychological Research*, *72*(6), 630–
714 640. <https://doi.org/10.1007/s00426-008-0165-3>
- 715 Deubel, H., Bridgeman, B., & Schneider, W. X. (1998). Immediate post-saccadic information
716 mediates space constancy. *Vision Research*, *38*(20), 3147–3159. [https://doi.org/10.1016/S0042-](https://doi.org/10.1016/S0042-6989(98)00048-0)
717 [6989\(98\)00048-0](https://doi.org/10.1016/S0042-6989(98)00048-0)
- 718 Deubel, H., & Schneider, W. X. (1996). Saccade target selection and object recognition: Evidence

719 for a common attentional mechanism. *Vision Research*, 36(12), 1827–1837.
720 [https://doi.org/10.1016/0042-6989\(95\)00294-4](https://doi.org/10.1016/0042-6989(95)00294-4)

721 Deubel, H., Schneider, W. X., & Bridgeman, B. (1996). Postsaccadic target blanking prevents
722 saccadic suppression of image displacement. *Vision Research*, 36(7), 985–996.
723 [https://doi.org/10.1016/0042-6989\(95\)00203-0](https://doi.org/10.1016/0042-6989(95)00203-0)

724 Doré-Mazars, K., Pouget, P., & Beauvillain, C. (2004). Attentional selection during preparation of
725 eye movements. *Psychological Research*, 69(1–2), 67–76. [https://doi.org/10.1007/s00426-003-](https://doi.org/10.1007/s00426-003-0166-1)
726 0166-1

727 Fracasso, A., Caramazza, A., & Melcher, D. (2010). Continuous perception of motion and shape
728 across saccadic eye movements. *Journal of Vision*, 10(13), 1–17.
729 <https://doi.org/10.1167/10.13.14>

730 Ganmor, E., Landy, M. S., & Simoncelli, E. P. (2015). Near-optimal integration of orientation
731 information across saccades. *Journal of Vision*, 15(16). <https://doi.org/10.1167/15.16.8>

732 Gillen, C., Weiler, J., & Heath, M. (2013). Stimulus-driven saccades are characterized by an invariant
733 undershooting bias: No evidence for a range effect. *Experimental Brain Research*, 230(2), 165–174.
734 <https://doi.org/10.1007/s00221-013-3640-z>

735 Hamker, F. H., Zirnsak, M., & Lappe, M. (2008). About the influence of post-saccadic mechanisms
736 for visual stability on peri-saccadic compression of object location. *Journal of Vision*, 8(14).
737 <https://doi.org/10.1167/8.14.1>

738 Harrison, W. J., Mattingley, J. B., & Remington, R. W. (2013). Eye movement targets are released
739 from visual crowding. *Journal of Neuroscience*, 33(7), 2927–2933.
740 <https://doi.org/10.1523/JNEUROSCI.4172-12.2013>

741 Hayhoe, M., Lachter, J., & Feldman, J. (1991). Integration of form across saccadic eye movements.
742 *Perception*, 20(3), 393–402. <https://doi.org/10.1068/p200393>

743 Hoffman, J. E., & Subramaniam, B. (1995). The role of visual attention in saccadic eye movements.
744 *Perception & Psychophysics*, 57(6), 787–795. <https://doi.org/10.3758/BF03206794>

745 Irving, E. L., Steinbach, M. J., Lillakas, L., Babu, R. J., & Hutchings, N. (2006). Horizontal saccade
746 dynamics across the human life span. *Investigative Ophthalmology and Visual Science*, 47(6), 2478–

747 2484. <https://doi.org/10.1167/iovs.05-1311>

748 Irwin, D. E. (1996). Integrating Information Across Saccadic Eye Movements. *Current Directions in*
749 *Psychological Science*, 5(3), 94–100. <https://doi.org/10.1111/1467-8721.ep10772833>

750 Irwin, D. E., & Robinson, M. M. (2015). Detection of Stimulus Displacements Across Saccades is
751 Capacity-Limited and Biased in Favor of the Saccade Target. *Frontiers in Systems Neuroscience*, 9,
752 161. <https://doi.org/10.3389/fnsys.2015.00161>

753 Joosten, E. R. M., & Collins, T. (2018). Probing transsaccadic correspondence with reverse
754 correlation. *Journal of Vision*, 18(3), 10–10. <https://doi.org/10.1167/18.3.10>

755 Khan, A. Z., Blohm, G., Pisella, L., & Munoz, D. P. (2015). Saccade execution suppresses
756 discrimination at distractor locations rather than enhancing the saccade goal location. *European*
757 *Journal of Neuroscience*, 41(12), 1624–1634. <https://doi.org/10.1111/ejn.12923>

758 Khan, A. Z., Heinen, S. J., & McPeck, R. M. (2010). Attentional cueing at the saccade goal, not at
759 the target location, facilitates saccades. *Journal of Neuroscience*, 30(16), 5481–5488.
760 <https://doi.org/10.1523/JNEUROSCI.4437-09.2010>

761 Kowler, E., Anderson, E., Doshier, B., & Blaser, E. (1995). The role of attention in the programming
762 of saccades. *Vision Research*, 35(13), 1897–1916. [https://doi.org/10.1016/0042-6989\(94\)00279-](https://doi.org/10.1016/0042-6989(94)00279-U)
763 U

764 Lakens, D. (2013). Calculating and reporting effect sizes to facilitate cumulative science: A practical
765 primer for t-tests and ANOVAs. *Frontiers in Psychology*, 4(NOV).
766 <https://doi.org/10.3389/fpsyg.2013.00863>

767 Li, H.-H., Barbot, A., & Carrasco, M. (2016). Saccade Preparation Reshapes Sensory Tuning. *Current*
768 *Biology*, 26(12), 1564-1570. <https://doi.org/10.1016/j.cub.2016.04.028>

769 Ludwig, C. J. H., Davies, J. R., & Eckstein, M. P. (2014). Foveal analysis and peripheral selection
770 during active visual sampling. *Proceedings of the National Academy of Sciences of the United States of*
771 *America*, 111(2), 291-299. DOI: 10.1073/pnas.1313553111

772 Macknik, S. L., & Livingstone, M. S. (1998). Neuronal correlates of visibility and invisibility in the
773 primate visual system. *Nature Neuroscience*, 1(2), 144–149. <https://doi.org/10.1038/393>

- 774 Mathôt, S., & Theeuwes, J. (2011). Visual attention and stability. In *Philosophical Transactions of the*
775 *Royal Society B: Biological Sciences* (Vol. 366, Issue 1564, pp. 516–527). Royal Society.
776 <https://doi.org/10.1098/rstb.2010.0187>
- 777 Melcher, D. (2011). Visual stability. *Philosophical Transactions of the Royal Society B: Biological Sciences*,
778 *366*(1564), 468–475. <https://doi.org/10.1098/rstb.2010.0277>
- 779 Mikula, L., Jacob, M., Tran, T., Pisella, L., & Khan, A. Z. (2018). Spatial and temporal dynamics of
780 presaccadic attentional facilitation before pro- and antisaccades. *Journal of Vision*, *18*(11), 1–16.
781 <https://doi.org/10.1167/18.11.2>
- 782 Niemeier, M., Crawford, J. D., & Tweed, D. B. (2003). Optimal transsaccadic integration explains
783 distorted spatial perception. *Nature*, *422*(6927), 76–80. <https://doi.org/10.1038/nature01439>
- 784 Nuthmann, A., Vitu, F., Engbert, R., & Kliegl, R. (2016). No Evidence for a Saccadic Range Effect
785 for Visually Guided and Memory-Guided Saccades in Simple Saccade-Targeting Tasks. *PLOS*
786 *ONE*, *11*(9), e0162449. <https://doi.org/10.1371/journal.pone.0162449>
- 787 Ohl, S., Kuper, C., & Rolfs, M. (2017). Selective enhancement of orientation tuning before saccades.
788 *Journal of Vision*, *17*(13), 2. doi: <https://doi.org/10.1167/17.13.2>.
- 789 Poth, C. H., Herwig, A., & Schneider, W. X. (2015). Breaking Object Correspondence Across
790 Saccadic Eye Movements Deteriorates Object Recognition. *Frontiers in Systems Neuroscience*,
791 *9*(DEC), 176. <https://doi.org/10.3389/fnsys.2015.00176>
- 792 Rolfs, M. (2015). Attention in Active Vision: A Perspective on Perceptual Continuity Across
793 Saccades. *Perception*, *44*(8–9), 900–919. <https://doi.org/10.1177/0301006615594965>
- 794 Rolfs, M., & Carrasco, M. (2012). Rapid simultaneous enhancement of visual sensitivity and
795 perceived contrast during saccade preparation. *Journal of Neuroscience*, *32*(40), 13744–13752.
796 <https://doi.org/10.1523/JNEUROSCI.2676-12.2012>
- 797 Rolfs, M., Jonikaitis, D., Deubel, H., & Cavanagh, P. (2011). Predictive remapping of attention
798 across eye movements. *Nature Neuroscience*, *14*(2), 252–258. <https://doi.org/10.1038/nn.2711>
- 799 Schneider, W. X., & Deubel, H. (1995). Visual attention and saccadic eye movements: Evidence for
800 obligatory and selective spatial coupling. In *Studies in Visual Information Processing* (Vol. 6, Issue
801 C, pp. 317–324). North-Holland. [https://doi.org/10.1016/S0926-907X\(05\)80027-3](https://doi.org/10.1016/S0926-907X(05)80027-3)

802 Schut, M. J., Van der Stoep, N., Fabius, J. H., & Van der Stigchel, S. (2018). Feature integration is
803 unaffected by saccade landing point, even when saccades land outside of the range of regular
804 oculomotor variance. *Journal of Vision*, *18*(7), 1–17. <https://doi.org/10.1167/18.7.6>

805 Stewart, E. E. M., & Schütz, A. C. (2018). Attention modulates trans-saccadic integration. *Vision*
806 *Research*, *142*, 1–10. <https://doi.org/10.1016/j.visres.2017.11.006>

807 Szinte, M., Jonikaitis, D., Rolfs, M., Cavanagh, P., & Deubel, H. (2016). Presaccadic motion
808 integration between current and future retinotopic locations of attended objects. *Journal of*
809 *Neurophysiology*, *116*(4), 1592–1602. <https://doi.org/10.1152/jn.00171.2016>

810 Tatler, B. W., & Land, M. F. (2011). Vision and the representation of the surroundings in spatial
811 memory. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *366*(1564), 596–610.
812 <https://doi.org/10.1098/rstb.2010.0188>

813 Trommershäuser, J., Glimcher, P. W., & Gegenfurtner, K. R. (2009). Visual processing, learning and
814 feedback in the primate eye movement system. In *Trends in Neurosciences* (Vol. 32, Issue 11, pp.
815 583–590). Elsevier Current Trends. <https://doi.org/10.1016/j.tins.2009.07.004>

816 Trommershäuser, J., Maloney, L. T., & Landy, M. S. (2003). Statistical decision theory and trade-offs
817 in the control of motor response. *Spatial Vision*, *16*(3–4), 255–275.
818 <https://doi.org/10.1163/156856803322467527>

819 Van der Stigchel, S., Schut, M. J., Fabius, J., & Van der Stoep, N. (2020). Transsaccadic perception is
820 affected by saccade landing point deviations after saccadic adaptation. *Journal of Vision*, *20*(9), 1–
821 12. <https://doi.org/10.1167/JOV.20.9.8>

822 Van Eccelpoel, C., Germeys, F., De Graef, P., & Verfaillie, K. (2008). Coding of identity-diagnostic
823 information in transsaccadic object perception. *Journal of Vision*, *8*(14), 1–16.
824 <https://doi.org/10.1167/8.14.29>

825 van Opstal, A. J., & van Gisbergen, J. A. M. (1989). A Model for Collicular Efferent Mechanisms
826 Underlying the Generation of Saccades. *Brain, Behavior and Evolution*, *33*(2–3), 90–94.
827 <https://doi.org/10.1159/000115906>

828 Vaziri, S., Diedrichsen, J., & Shadmehr, R. (2006). Why does the brain predict sensory consequences
829 of oculomotor commands? Optimal integration of the predicted and the actual sensory

830 feedback. *Journal of Neuroscience*, 26(16), 4188–4197.
831 <https://doi.org/10.1523/JNEUROSCI.4747-05.2006>

832 Wexler, M., & Collins, T. (2014). Orthogonal steps relieve saccadic suppression. *Journal of Vision*,
833 14(2), 1–9. <https://doi.org/10.1167/14.2.13>

834 White, A. L., Rolfs, M., & Carrasco, M. (2013). Adaptive deployment of spatial and feature-based
835 attention before saccades. *Vision Research*, 85, 26–35.
836 <https://doi.org/10.1016/j.visres.2012.10.017>

837 Wick, F. A., Garaas, T. W., & Pomplun, M. (2016). Saccadic adaptation alters the attentional field.
838 *Frontiers in Human Neuroscience*, 10(NOV2016). <https://doi.org/10.3389/fnhum.2016.00568>

839 Wolf, C., & Schütz, A. C. (2015). Trans-saccadic integration of peripheral and foveal feature
840 information is close to optimal. *Journal of Vision*, 15(16), 1–1. <https://doi.org/10.1167/15.16.1>

841 Wurtz, R. H. (2008). Neuronal mechanisms of visual stability. *Vision Research*, 48(20), 2070–2089.
842 <https://doi.org/10.1016/j.visres.2008.03.021>

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844 **Supplemental table 1**845 **Excluded trials for experiment 1**

Exclusion	Number of trials	% of total trials/mean across participants*	Number of participants who had such trials	Range across participants (trials)	SD across participants
Camera lost eye position/participant blinked/participant made more than one saccade	257	6.69%	10/10	7-74/384	5.86%
Response >10s	4	0.1%	2/10	1-3	0.25%
Saccade latencies less than 100ms	4	0.1%	3/10	1-2	0.18%
Saccade latencies more than 600 ms	5	0.13%	5/10	1-1	0.14%
Eye fixation more than 1.5cm away from centre	57	1.48%	9/10	2-15	1.24%
Saccade offset before DS offset	5	0.13%	2/10	2-3	0.28%
Saccade direction outside of 10°/saccade amplitude <3.8° or >7.8°	477	12.42%	10/10	19-105	7.59%

846 * because of the even number of trials for each participant the total % and mean % across
847 participants is identical

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849 **Supplemental table 2**850 **Excluded trials for experiment 2 parallel condition**

Exclusion	Number of trials	% of total trials/mean across participants	Number of participants who had such trials	Range across participants (trials)	SD across participants
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Camera lost eye position/participant blinked/participant made more than one saccade	736	7% (6.2%)	19/19	3-168/304-756	6.7%
Response >10s	22	0.21%(0.25%)	4/19	1-17	0.92%
Saccade latencies less than 100ms	47	0.45%(0.33%)	4/19	1-42	1.27%
Saccade latencies more than 600 ms	323	3.08%(2.4%)	10/19	1-262	7.88%
Eye fixation more than 1.5cm away from centre	202	1.92%(1.75%)	16/19	1-84	3.18%
Saccade offset before DS offset	12	0.11%(0.13%)	2/19	1-11	0.5%
Saccade direction outside of 20°/saccade amplitude <3° or >7°	327	3.11%(3.18%)	19/19	4-60	3.18%

851

852 **Excluded trials for experiment 2 perpendicular condition**

Exclusion	Number of trials	% of total trials/mean across participants	Number of participants who had such trials	Range across participants (trials)	SD across participants
Camera lost eye position/participant blinked/participant made more than one saccade	339	7.54%(7.36%)	12/12	4-75/300-500	5.35%
Response >10s	7	0.16%(0.16%)	3	1-4	0.33%
Saccade latencies less than 100ms	0	-	-	-	-
Saccade latencies more than 600 ms	236	5.25%	6	1-197	14.0%
Eye fixation more than 1.5cm away from centre	116	2.58%(2.46%)	11	1-33	2.87%
Saccade offset before DS offset	30	0.67%(0.63%)	1	30	-
Saccade direction	67	1.49%(1.43%)	11	2-16	0.97%

outside of 20°/saccade amplitude <3° or >7°					
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