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Automatic and intentional influences on saccade landing

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11 **Abstract**

12 Saccadic eye-movements enable us to rapidly direct our high-resolution fovea onto relevant parts of
13 the visual world. However, while we can intentionally select a location as a saccade target, the wider
14 visual scene also influences our executed movements. In the presence of multiple objects, eye-
15 movements may be “captured” to the location of a distractor object, or be biased towards the
16 intermediate position between objects (the "global effect"). Here we examined how the relative
17 strengths of the global effect and visual object capture changed with saccade latency, the separation
18 between visual items and stimulus contrast. Importantly, while many previous studies have omitted
19 giving observers explicit instructions, we instructed participants to either saccade to a specified
20 target object or to the midpoint between two stimuli. This allowed us to examine how their explicit
21 movement goal influenced the likelihood that their saccades terminated at either the target,
22 distractor, or intermediate locations. Using a probabilistic mixture model, we found evidence that
23 both visual object capture and the global effect co-occurred at short latencies and declined as
24 latency increased. As object separation increased, capture came to dominate the landing positions
25 of fast saccades, with reduced global effect. Using the mixture model fits we dissociated the
26 proportion of unavoidably captured saccades to each location from those intentionally directed to
27 the task goal. From this we could extract the time-course of competition between automatic capture
28 and intentional targeting. We show that task instructions substantially altered the distribution of
29 saccade landing points, even at the shortest latencies.

30

31 **Significance Statement**

32 When making an eye-movement to a target location, the presence of a nearby distractor can cause
33 the saccade to unintentionally terminate at the distractor itself or the average position in-between
34 stimuli. With probabilistic mixture models, we quantified how both unavoidable capture and goal-
35 directed targeting were influenced by changing the task and the target-distractor separation. Using
36 this novel technique, we could extract the time-course over which automatic and intentional
37 processes compete for control of saccades.

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39 **Keywords:** Global Effect, target selection, top-down selection, oculomotor capture

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45 **1. Introduction**

46 Saccades are rapid, ballistic eye movements that facilitate our ability to process information
47 from our surroundings. By shifting the target of our gaze to a new location, saccades allow us to
48 direct our high-resolution fovea to locations of interest for fine-grained visual processing. Many of
49 these eye-movements are automatic and reactionary, with our gaze shifting rapidly towards a
50 flashing light or an abruptly moving stimulus. These unconscious responses make ecological sense,
51 as they help ensure that both our fovea and our attention can be directed to potential threats as
52 quickly as possible. As such it is perhaps unsurprising that the likely targets for saccadic eye-
53 movements can be quite well predicted by the low-level properties of the visual scene (Theeuwes,
54 1994; Itti and Koch, 2001; Serences and Yantis, 2006). However, at other times individuals view a
55 scene with specific aims or goals in mind. Rather than passively responding to visual saliency, here
56 they actively investigate their visual environment and intentionally direct their eye-movements
57 towards the task goal (if it is known) or towards the regions within the scene thought most likely to
58 contain the task-relevant information (Bacon and Egeth, 1994; Folk and Remington, 1998; Folk et al.,
59 1992, 1994; Serences and Yantis, 2006).

60 For example, when searching for a friend on a crowded street, an individual should direct their
61 eye-movements towards the last location they saw their friend, rather than towards the most salient
62 features in the scene, to improve the chances of finding them quickly. To achieve this intentional
63 targeting the visual system exerts top-down control over the programming of the eye-movement
64 (Yantis, 1993; van Zoest et al., 2004; Serences and Yantis, 2006). This task-related signal is thought to
65 inhibit the automatic capture towards salient stimuli and boosts neural activity corresponding to
66 specific task-relevant locations, assisting in the attentional selection of these regions. Here we
67 explore the interactions between automatic and intentional targeting and examine how the
68 competition between these processes changes depending on both the proximity of objects in the
69 visual world and the delay (and hence available processing time) before initiating the eye-
70 movement. To achieve this, we manipulated the spatial separation between visual objects and
71 investigated how varying the goal location with different task instructions influenced the distribution
72 of saccade landing positions in response to the sudden appearance of two objects.

73 In sparse visual scenes, the sudden appearance of a visual stimulus triggers a fast, accurate
74 saccade towards its location (Jonides and Yantis, 1988; Yantis, 1993; Franconeri et al., 2004). This
75 eye-movement is typically considered to be automatic, occurring without the observer's explicit
76 intention to move their eyes, and requires intentional suppression if the individual is to either
77 maintain their fixation or to instead initiate a saccade to another location (Theeuwes et al., 1998).
78 Indeed, even when individuals are specifically attempting an alternative eye-movement, the sudden
79 appearance of a distractor stimulus will often instead capture their gaze to its location (Boot et al.,

80 2005; Godijn and Theeuwes, 2002; Irwin et al., 2000; Ludwig and Gilchrist, 2003; Ludwig et al., 2008;
81 Theeuwes et al., 1998, 1999; Wu and Remington, 2003). While the strength of this oculomotor
82 capture can be modulated (e.g. with task instructions; Wu and Remington, 2003), even with strong
83 manipulations it is difficult to fully eliminate the capture towards abrupt onsets. These results point
84 to a fundamental role of low-level stimulus salience in causing stimulus capture and suggest that
85 neither top-down control nor changes to the low-level properties of the stimuli can entirely
86 extinguish the stimulus-driven selection of a distractor as a potential saccade target.

87 While the appearance of a single stimulus might lead to oculomotor capture, when multiple
88 stimuli appear simultaneously in close proximity the landing position of the resulting saccade is often
89 biased towards an intermediate location between the stimuli. This spatial bias is known as “the
90 global effect” (Coren and Hoenig, 1972; Findlay, 1982). Interestingly, the global effect has been
91 found to occur even when the visual stimuli are sufficiently differentiated so that the target and
92 distractor are unambiguous (Coren and Hoenig, 1972; Findlay, 1982; Jacobs, 1987; Ottes et al., 1985;
93 Van der Stigchel and Nijboer, 2013; Walker et al., 1997). This suggests that the effect does not arise
94 due to decision confusion in identifying the target stimulus. Indeed, the prevalence of the global
95 effect does not vary as a function of target and distractor discriminability (Jacobs, 1987).
96 Furthermore, even in tasks in which both stimuli are potential targets (i.e. the participant must
97 simply saccade to either stimulus) the global effect is still observed. However, manipulations of low-
98 level properties of the stimuli, that do not change the discriminability of the target per se, such as
99 manipulating their relative salience (Deubel et al., 1984; Findlay, 1982; Findlay et al., 1993) can
100 substantially modulate the proportion of global effect saccades observed. These findings suggest
101 that the global effect arises from similarity in the visual properties of the stimuli causing competition
102 in automatic target selection processes. These effects have been modelled in terms of activity in the
103 superior colliculus (SC; Meeter et al., 2010; Trappenberg et al., 2001; Viswanathan and Barton,
104 2013).

105 The delay before participants initiate their eye-movement is also important. Indeed, the
106 strongest biases in landing position towards the average location have consistently been found for
107 shorter saccade latencies, while longer delays lead to increasingly accurate eye-movements (Chou et
108 al., 1999; Coëffé and O’Regan, 1987; Edelman and Keller, 1998; Eggert et al., 2002; Findlay, 1982;
109 Godijn and Theeuwes, 2002; Heeman et al., 2014; Jacobs, 1987; McSorley and Findlay, 2003; Ottes
110 et al., 1985; Van der Stigchel and Nijboer, 2011, 2013; Vitu et al., 2006). For example, Ottes and
111 colleagues (1985) demonstrated that while the most rapid subset of saccades exhibited a substantial
112 global effect, those in which the saccade was executed longer than 300 ms after the appearance of
113 the stimuli were completely accurate. This time-course, in which only those saccades initiated
114 rapidly after stimulus appearance will reliably generate an averaging saccade, has been consistently

115 observed across different studies (Eggert et al., 2002; McSorley and Findlay, 2003) and has been
116 attributed to the top-down effects of goal-related selection influencing target selection (van Zoest et
117 al., 2004). This suggests that the global effect is a latency-sensitive process originating from the
118 automatic, exogenous processing of abruptly appearing visible stimuli.

119 The relative separation between visual stimuli is another critical factor in the generation of
120 averaging saccades. For stimuli appearing outside of the immediate 1.5° of visual angle surrounding
121 the current fixation (the “foveal dead zone”; Vitu, 2008), the boundary between predominantly
122 averaging saccades and predominantly individualized saccades has been consistently reported at
123 target-distractor separations of 20-30° in angular distance (Ottes et al., 1984; Van der Stigchel and
124 Nijboer, 2011, 2013; Vitu, 2008; Walker et al., 1997). For example, Ottes and colleagues (1984)
125 showed a distinct averaging effect when two targets were separated by 30°, but bimodal responses
126 when they were separated by 90°. Similarly, the work of Walker and colleagues (1997) suggested
127 that only distractors occurring within a strict $\pm 20^\circ$ angular window surrounding the target altered
128 saccade amplitude. However, some more recent studies have shown evidence of averaging saccades
129 occurring at larger separations (Arai et al., 2004; Van der Stigchel and Nijboer, 2011; Van der Stigchel
130 et al., 2009, 2012). This raises the possibility that, rather than a strictly defined window, the
131 transition between accurate and averaging saccades might be more gradual.

132 In one of the most detailed studies of the spatial range of the global effect, Van der Stigchel
133 and Nijboer (2013) examined a variety of different target and distractor separations (between 12.5°
134 and 55°). Rather than relying upon the mean saccade landing position, which can often conflate
135 saccades erroneously directed to the distractor object with those targeting the global location, they
136 instead quantified the strength of the global effect by comparing unimodal and bimodal fits to the
137 data. They found that only separations smaller than 45° were better fit by a unimodal distribution
138 and, although they did observe some averaging saccades beyond this range, they concluded that the
139 global effect does not occur beyond 55° separation. However, their analyses did not allow for the
140 possibility that the observed saccade landing distribution incorporated a mixture of stimulus capture
141 (to either the target or distractor location) and averaging saccades. Additionally, when two stimuli
142 appear simultaneously, the average latency of saccades decreases as the separation between the
143 stimuli increases. This effect is known as the remote distractor effect (RDE; Walker et al., 1997) and,
144 since for the same spatial separation the strength of the global effect decreases as saccade latency
145 increases, by analyzing their data irrespective of saccade latency the true prevalence of the global
146 effect at larger separations may have been obscured.

147 The behavioral and neural evidence, both from human (Chou et al., 1999) and animal studies
148 (Dorris et al., 2007; Edelman and Keller, 1998; Glimcher and Sparks, 1993; Opstal and Gisbergen,
149 1990) has broadly supported the idea that the global effect occurs because potential saccade targets

150 are encoded as vectors within a neural population code (Tipper et al., 1997). In this framework,
151 competition between the vector representing the target and that of the distractor drives both the
152 delays in saccade initiation and saccade averaging (Meeter et al., 2010; Rizzolatti et al., 1987; Sheliga
153 et al., 1995; Trappenberg et al., 2001). The slowing of saccadic reaction times due to the presence of
154 a distractor (remote distractor effect) arises from the visible stimuli mutually inhibiting each other,
155 slowing the overall rate at which activity accumulates towards the threshold of movement initiation.
156 When these stimuli are sufficiently close, instead of inhibiting one another they are instead treated
157 as a single activation. While this release from inhibition allows saccades to be initiated more rapidly,
158 it also results in a bias of the executed saccades towards the average (global effect) location. These
159 populations have been postulated to reside within the superior colliculus (Glimcher and Sparks,
160 1993), an area where signals from multiple brain regions including the parietal eye fields, frontal eye
161 fields and sensory areas are integrated (Moschovakis et al. 1996; Guitton et al. 2004).

162 However, the existence of the long-distance lateral inhibitory connections required by neural
163 models of SC is debated (Arai et al., 2004; Isa and Hall, 2009; Lee and Hall, 2006; Marino et al., 2015).
164 This has led researchers to question whether saccadic behavior truly results from simple population
165 codes in SC or if it is better explained by interactions between low-level oculomotor processes and
166 decision-making processes emerging from other areas (Christie et al., 2015). Although electrical
167 stimulation of the SC has been shown to elicit saccades to the corresponding spatial location,
168 stimulation of multiple locations simultaneously results in averaging saccades to the intermediate
169 location (Glimcher and Sparks, 1993). Interestingly, as noted by Christie and colleagues (2015), this
170 averaging in response to stimulation occurred for separations that far exceeded the spatial window
171 in which behavioral averaging is typically observed. Coupled with their own findings, in which they
172 examined the influence of spatially specific priming on saccadic reaction times, this led them to
173 suggest that the transition from averaging saccades to stimulus-specific saccades may not occur in
174 SC. Instead they propose that the average location is always the dominant activity on the saccade
175 map and the tendency to saccade accurately at larger separations occurs due to the influence of
176 “high-level decision making processes” (p1548) as participants attempt to fulfil their assigned task
177 (i.e. selecting a specific target for their eye-movement; Christie et al., 2015).

178 Alternatively, while their priming paradigm may have functioned as a good probe for the
179 effects of stimulus activity in SC, the presence of the priming stimuli may have led to inhibition of
180 these locations as potential motor goals. Using an anti-saccade task, Viswanathan and Barton (2013)
181 have previously demonstrated that global effects were elicited by distractors that were positioned
182 close to the task goal, and not by the stimulus location per se. Based on this, they suggested that the
183 global effect occurs because of interactions between competing movement goals without
184 necessarily influencing stimulus localization. When comparing saccades of similar latency, they

185 found that anti-saccades elicited a stronger global effect, with this difference consistent with the
186 idea that the lower activity at the saccade goal during anti-saccades (Everling et al., 1999) results in a
187 greater relative influence of the distractor. As, in such a task, the intermediate position between
188 physical stimuli is located far from the intermediate position between the inferred-goal location and
189 the distractor, these results suggest that this activity must incorporate top-down knowledge of the
190 task. Applied to the results of Christie and colleagues (2015), the inhibition of the prime locations as
191 potential goal locations (to prevent automatic saccades until the appearance of the go stimulus)
192 could have resulted in the broad, separation-invariant reduction in saccadic reaction times that they
193 observed.

194 The influence of saccade latency on the frequency of averaging saccades is typically thought to
195 represent an increased role of top-down selection of the task-goal as the delay before movement
196 initiation increases (van Zoest et al., 2004, 2012). Thus, while low latency saccades are thought to
197 reveal competition occurring between ascending sensory information, those initiated later are
198 dominated by the influence of intentional, top-down selection of the goal location. This makes task
199 instructions critical, as they directly affect the intentional selection of the movement goal. Indeed,
200 previous studies have demonstrated that simply emphasizing to participants the requirement to
201 make a highly accurate eye-movement reduces the likelihood of making saccades to the global effect
202 location (Coren and Hoenig, 1972; Findlay, 1982; Findlay and Kapoula, 1992). Both paradigms in
203 which participants must saccade to a target stimulus in the presence of a clearly differentiated
204 distractor stimulus (saccade to target; STT), and those in which participants are shown two potential
205 targets stimuli and are instructed to saccade to either (saccade to either; STE) have been found to
206 result in a considerable global effect (Van der Stigchel and Nijboer, 2011), although the task-related
207 processes that would occur in such a task would arguably differ substantially.

208 Despite this important role of task instructions, a frequently used alternative paradigm,
209 ostensibly to eliminate the influence of top-down selection, is to present two identical stimuli and to
210 give the participants ambiguous instructions as to what is the task goal (i.e. “participants were
211 instructed to move their eyes as fast as possible to the stimuli presented”; page 31; Heeman et al.,
212 2014). In this task, which we will term saccade-to-ambiguous (STA), the task instructions are
213 deliberately vague as to what is the explicit task goal. Typically, these studies report a stronger
214 global effect and argue that, in the absence of top-down control, saccades predominantly land at the
215 midpoint of the stimuli as this is the “default” behavior (e.g. Silvis and Van der Stigchel, 2014).
216 However, the absence of explicit instructions about the task goal does not prevent participants from
217 inferring what they think is required of them, and, when unsure where to look, executing an eye-
218 movement to the midpoint (bringing both stimuli closer to the fovea) is indeed a valid strategy. To
219 dissociate the task goal from eye-movements to either location, we developed a novel task in which

220 participants are required to either deliberately saccade to a target stimulus or to the intermediate
221 location in-between stimuli. By comparing the tasks, we could then assess how intentional selection
222 alters the distribution of saccade landing positions.

223 **Aims and outline**

224 We aimed to investigate how the spatial separation between two targets influences both the
225 speed at which saccades are initiated, and the tendency to execute saccades to the average location.
226 We examined saccades towards a target stimulus in the presence of a distractor separated by up to
227 75 degrees. We quantified the frequency of executing an averaging global effect saccade under
228 these different conditions by fitting the data with probabilistic mixture models and, through
229 examination of several different variations of the models, determining which components were
230 necessary to fit the observed saccade landing distributions for each of our different conditions. This
231 approach enabled us to make very sensitive estimates of the proportion of saccades captured
232 towards either the target, distractor, or intermediate location. Additionally, we sought to explicitly
233 examine the influence of task instructions by varying whether participants were instructed to
234 saccade to the target location or to the intermediate location between the two stimuli. This
235 additional manipulation revealed the interactions across time between automatic stimulus capture,
236 the global effect and intentional top-down selection.

237

238 **2. Experiment 1**

239 In the first experiment, we investigated how different target-distractor separations influence
240 the prevalence of the global effect and how this relationship changes with the latency of the
241 saccade. Additionally, in separate blocks we varied the instructions to participants, asking them to
242 either execute a saccade to the target object (defined by color) or to the intermediate position
243 between the two objects. This manipulation enabled us to examine the proportion of saccades
244 unavoidably directed towards the target, distractor, or intermediate location regardless of which
245 was the task-goal location. By contrasting the landing distributions for the same separation across
246 the two tasks, we additionally quantified the role of top-down processes in determining saccade
247 targets.

248

249 **2.1. Methods**

250

251 **Participants**

252 Eight naive individuals (20–29 years old; 2 male) took part in the experiment. All participants
253 had normal or corrected-to-normal visual acuity. Informed consent was obtained prior to the study
254 in accordance with the guidelines of the Helsinki Declaration.

255

256 **Apparatus**

257 Participants were seated comfortably, with their head stabilized by a chin rest, within a black
258 felt-clad housing that extended from the monitor to behind the participant’s head. This eliminated
259 peripheral distractions and ensured that only the testing monitor was visible to them. Participants
260 viewed the experiment on a 21-inch linearized CRT monitor operating at 85 Hz and viewed at 60 cm.
261 Eye-movements were monitored by measuring each participant’s right eye using an infra-red video-
262 based eye tracker (Eyelink 1000 desktop system; SR Research Ltd., Canada) operating at 1000 Hz.

263

264 **Stimuli and procedure**

265 The experiment consisted of two separate tasks which differed only in the instructions given
266 to the participants (Figure 1). In the two task conditions the instructions were to either “move your
267 eyes as fast as possible to the object that matches the same color as the fixation object” (saccade to
268 target; STT) or “move your eyes as fast as possible to the point in-between the two objects” (saccade
269 to middle; STM). The stimuli and experimental procedure remained identical between the two tasks,
270 with the participant simply instructed to ignore the colors of the fixation and stimuli during the STM
271 task. The order of tasks was counter-balanced across participants and the experiment was organized
272 so that participants completed all the blocks of one task before beginning the second task. All the
273 blocks for each task were completed within a single day, with a separation of at least one day before
274 participants began the blocks of the other task.

275

<< **FIGURE 1 ABOUT HERE** >>

276 Each trial began with the appearance of a white-colored stimulus in the center of the display
277 (figure 1). After 200 ms of steady fixation the experimental trial began and the color of the stimulus
278 changed to the target color. After 1500–2000 ms two peripheral stimuli appeared at 8° in the
279 periphery and the fixation stimulus disappeared. This disappearance was the cue for the participants
280 to move their gaze as rapidly as possible to the goal location. The separation between target and
281 distractor was either 15°, 30°, 45°, 60° or 75° for both tasks with an additional single target (no
282 distractor) condition in the STT task. The angle at which the stimuli appeared was randomized and,
283 in conditions in which there was a target stimulus, the distractor could appear either clockwise or
284 counter-clockwise from the target stimulus. The online onset of the saccade was determined using
285 both a spatial (>1.5° from display center) and a velocity (>30°/sec) criterion, while the online offset

286 was determined when velocity dropped below 30°/sec. Upon detection of the saccade onset the
287 stimuli were extinguished and, once the saccade offset was detected, a response bar extending from
288 the fixation to 10° in the periphery appeared. The angle of the bar was initially random, but
289 participants could manipulate its position via the mouse cursor to indicate the location of the task
290 goal. This meant that, after making their eye-movement (and regardless of the accuracy of their eye-
291 movement), participants were required to give an additional perceptual response about the location
292 of the task goal. This allowed us to examine whether perceptual localization of the goal location also
293 varied when eye-movements were directed towards non-goal locations.

294 Following this response, participants were given feedback about the accuracy of their
295 perceptual response and the appropriateness of their saccade. Importantly, no feedback was given
296 regarding the accuracy of the eye-movement relative to the goal. Instead, the feedback informed
297 them about the magnitude of their saccade, to prevent excessive undershooting (as the error in
298 saccade angle scales with eccentricity), as well as the duration of the delay from when the stimuli
299 appeared to when they initiated their saccade. Participants were instructed to attempt to initiate
300 their eye-movement within 200 ms of the fixation disappearing and to monitor the feedback about
301 their saccade eccentricity to ensure they moved fully towards their intended location on each trial
302 (and did not make progressively shorter saccades as they fatigued). This feedback, about both their
303 saccade eccentricity and latency, encouraged participants to continue to make both accurate and
304 rapid eye-movements throughout the entire experiment. Additionally, the location of their
305 perceptual response, as well as the presented location of the target and distractor, was shown. After
306 a short delay, a white fixation object re-appeared at the screen center and the next trial was
307 initiated once participants had maintained their fixation at that location for more than 500 ms.

308 The colors of target and distractor objects were drawn without replacement from four
309 different color values. These were defined in LCH color space with a luminance of 50, chromaticity of
310 50 and hue varying to generate red (25), blue (280), green (170) and yellow (100) colors. Stimuli
311 themselves consisted of posterized white noise (split into 3 tones) with a medium contrast level
312 (RMS: 33%) surrounded by a colored outer ring with a central colored dot (figure 1A). The stimuli
313 were designed so the overall saliency of each stimulus could be varied by manipulating the contrast
314 of the internal noise patch, while the color identity of the stimulus (defined by the ring and central
315 dot) would remain discriminable.

316 Each session started with a custom thirteen-point calibration procedure consisting of
317 concentric circles. At the start of each trial there was a strict fixation check to ensure that eye-
318 position was still being accurately recorded. If this initial fixation check failed, the experimenter
319 could initiate either a drift correction or recalibration procedure. Trials were randomized such that
320 for each separation tested there was an equal distribution of all possible color pairs in each block.

321 Trials were automatically repeated within each block if the participant broke fixation (any deviation
322 from a 1.5° window around the fixation dot or movements exceeding 30°/sec) before it was time to
323 make the response saccade, initiated their saccade too fast (i.e. before the fixation disappeared) or
324 too slow (i.e. more than 400 ms after fixation disappeared), made a saccade less than half the
325 distance between the fixation object and the stimuli (i.e., < 4°), or if they blinked during the trial at
326 any time before they had completed their response saccade. These criteria, and the automatic
327 repetition of failed trials, ensured that there would be an approximately equal number of valid trials
328 in all conditions available for analysis.

329 Each task was tested separately, on different days, during a 90-minute session in which 10
330 blocks were completed for each task. Each block lasted approximately eight minutes and
331 participants were encouraged to take a small pause between blocks. At the beginning of each block
332 participants were verbally reminded of the experimental task to ensure that they were always aware
333 of their movement goal location.

334

335 **Data pre-processing**

336 In addition to errors detected online, we performed a more precise offline analysis to ensure
337 the inclusion criteria were met. In the offline analyses saccades were detected based on their
338 velocity distribution (Engbert and Mergenthaler, 2006) using a moving average over twenty
339 subsequent eye position samples. Saccade onset was detected when the velocity exceeded the
340 median of the moving average by 3 SDs for at least 20 ms. This enabled us to compute more
341 accurate offline times of saccade onset, offset and landing and to exclude any additional trials which,
342 despite passing the online analysis, did not meet inclusion criteria when the eye-movement was
343 analyzed in more detail. After this additional offline filtering, we were left with an average of 565
344 trials (94%) in the STM task and 683 trials (95%) in the STT task (which included the no distractor
345 condition). This meant that for both tasks each of the different target-distractor separation
346 conditions had approximately 113 trials available for analysis per participant.

347

348 **Modelling: Target, distractor, and intermediate locations**

349 To separate the proportion of saccades which were directed towards the target, intermediate,
350 or distractor locations we fit the data with a probabilistic mixture model, using a maximum
351 likelihood procedure (*fmincon* function of the statistics toolbox in MATLAB; The MathWorks, Natick,
352 MA). Throughout the manuscript, the goal location will refer to the intended saccade goal. In the STT
353 task, in which there was a clear distinction between the target and distractor stimulus, the target
354 stimulus was also the goal location, whereas in the STM task both stimuli together indicated the goal

355 without being located at the goal location themselves. Nonetheless, to provide consistency of
 356 analysis between the two conditions, we maintained the assignment of target and distractor
 357 categories in the STM task, and used these categories for modeling and statistical comparison
 358 purposes.

359 << FIGURE 2 ABOUT HERE >>

360 The full model (illustrated in Figure 2) consisted of a mixture of Gaussian components
 361 centered on the target, distractor, and intermediate locations, described as follows:

$$362 \quad p(x) = w_{tar} \phi(x; \mu_{tar}, \sigma_{tar}) + w_{int} \phi(x; \mu_{int}, \sigma_{int}) + w_{dis} \phi(x; \mu_{dis}, \sigma_{dis}), \quad (1)$$

363 where x is the saccade endpoint angle from the origin and $\phi(x; \mu, \sigma)$ is the normal probability
 364 density function with mean μ and standard deviation σ . Here the distribution of saccade landing
 365 positions can be described as the probabilistic mixture of saccades targeting either the target,
 366 distractor, or intermediate location. The target and distractor components (μ_{tar} and μ_{dis}) were
 367 centered on the actual locations at which the stimuli occurred, while the intermediate component
 368 was centered on the midpoint between them,

$$369 \quad \mu_{int} = \frac{\mu_{dis} + \mu_{tar}}{2}. \quad (2)$$

370 Rather than fitting σ_{tar} , σ_{dis} , and σ_{int} as free parameters, we fit just two parameters, α and β .
 371 The width of target and distractor components were set equal to each other and to the α parameter,

$$372 \quad \sigma_{tar} = \sigma_{dis} = \alpha, \quad (3)$$

373 whereas the width of the intermediate component was defined in terms of β , a ratio of the target-
 374 distractor separation, such that as the distance between the stimuli increased the width of the
 375 intermediate component also increased,

$$376 \quad \sigma_{int} = \beta |\mu_{dis} - \mu_{tar}|. \quad (4)$$

377 Prior exploratory analyses supported this relationship. The parameters α and β were shared
 378 across all target-distractor separations and both tasks. The resulting parameter estimates provided a
 379 close match to those found when each target-distractor separation and task was independently fit.

380 To determine the necessity of each of the components (e.g. whether the data could be
 381 explained just as well at some separations without the global effect), we derived two simpler
 382 variants of the model which consisted of either a single component centered on the intermediate
 383 location (global-effect-only; Eq 5) or two components centered on the target and distractor
 384 (stimulus-capture-only; Eq 6).

$$385 \quad p(x) = w_{int} \phi(x; \mu_{int}, \sigma_{int}) \quad (5)$$

386
$$p(x) = w_{tar} \phi(x; \mu_{tar}, \sigma_{tar}) + w_{dis} \phi(x; \mu_{dis}, \sigma_{dis}) \quad (6)$$

387 We fit each of these different models to the participants' data and computed the AICc (Akaike
 388 Information Criterion with correction for finite data). The AICc is a means for evaluating the
 389 appropriateness of different models (which may differ in their number of free parameters) for a
 390 given dataset. Importantly, this method is based on the likelihood of the fits and encompasses a
 391 penalty based on their number of free parameters, meaning that for a more complicated model to
 392 be more likely (i.e. be to have a lower AICc) it must explain more of the variance to make up for its
 393 additional parameters. To determine whether the full model was necessary, we expressed these
 394 scores as $\Delta AICc$ relative to the full model. This allows the differences between the full model and the
 395 alternative, simpler models to be clearly expressed. If an alternative model could describe the data
 396 better than the full model then it would have a $\Delta AICc$ score below 0. Thus, the $\Delta AICc$ allows us to
 397 examine the quality of models with different numbers of parameters to determine which is the best
 398 descriptor of the data. To quantify changes in the weights for the target, distractor, and
 399 intermediate components across time, or across different angular separations, we examined the
 400 average slope across subjects of a regression line fit through the weights. This average slope was
 401 then tested against zero to determine whether there was a significant trend across time.
 402 Additionally, to aid comparisons, we defined "short-latency-saccades" as those occurring less than
 403 200 ms after stimulus onset.

404

405 **Modelling: stimulus capture, global effect, and task goal**

406 To decompose the data into automatic and intentional components we compared the weights
 407 obtained from the full model across the two tasks. For clarity, these new combined weights will be
 408 referenced with a capital W, while the weights found within tasks will remain a lower-case w with
 409 the additional superscript indicating from which task they originate.

410 We first computed the influence of the task goal by taking the mean of the difference
 411 between the target weights in STT and STM task and the intermediate weights in the STM and STT
 412 task (eq. 7). This determines the mean change in the probability of landing at a given location when
 413 it is versus is not the task goal,

414
$$W_{goal} = \frac{(w_{tar}^{STT} - w_{tar}^{STM}) + (w_{int}^{STM} - w_{int}^{STT})}{2}. \quad (7)$$

415 We then computed the mean weight of unavoidable capture towards the global effect
 416 location across both tasks by averaging the intermediate component weight in the STT task with the
 417 intermediate component weight in the STM task less the newly derived weight of the task goal,

418
$$W_{global} = \frac{w_{int}^{STT} + (w_{int}^{STM} - W_{goal})}{2} . \quad (8)$$

419 The mean weight of unavoidable capture towards the distractor location was simply the
 420 average of the distractor component in both tasks,

421
$$W_{dis} = \frac{w_{dis}^{STT} + w_{dis}^{STM}}{2} . \quad (9)$$

422 The average weight of the capture towards the target location was the average of the target
 423 weight in the STT task, minus the newly derived weight of the task goal, and the weight of the target
 424 in the STM task,

425
$$W_{tar} = \frac{(w_{tar}^{STT} - W_{goal}) + w_{tar}^{STM}}{2} . \quad (10)$$

426 Together, the newly derived mean weights for target and distractor then sum to give the
 427 weight of capture towards stimulus locations,

428
$$W_{stim} = W_{dis} + W_{tar} . \quad (11)$$

429 The weights defined in this way sum to 1,

430
$$W_{stim} + W_{global} + W_{goal} = 1 . \quad (12)$$

431 Changes in the weights across time were quantified by finding the average slope across
 432 subjects of a line fit through the weights across time. This average slope was then tested against
 433 zero to determine whether there was a significant trend across time.

434

435 **2.2. Results and discussion**

436

437 **Saccade latency**

438 The different saccadic latencies for the two tasks and different angles of separation are
 439 shown

440 in figure 3A, with red indicating the STT task and green the STM task. The saccade latency for each
 441 participant was normalized to their median saccade latency at 15° target-distractor separation
 442 across both tasks. We normalized to the smallest separation, as opposed to the no distractor
 443 condition, to examine whether the saccade latency with two targets separated by 15° was different
 444 than the saccade latency with a single stimulus (figure 3).

445

<< FIGURE 3 ABOUT HERE >>

446

447

To examine whether the addition of a second stimulus influenced the saccade latency, we compared the 15° target-distractor separation condition for both tasks with the no distractor

448 condition. We found that there was no difference in the saccade latency for either the STT ($p = 0.60$;
449 $t(7) = 0.54$) or the STM ($p = 0.93$; $t(7) = 0.09$) tasks, suggesting that a 15° separation between the
450 target and distractor was insufficient to induce a remote distractor effect. Furthermore, this also
451 demonstrated that the mere presence of an additional stimulus did not alter median saccade
452 latency. Additionally, we found no difference at 15° target-distractor separation between the two
453 tasks ($p = 0.65$; $t(7) = 0.47$). However, as target-distractor separation increased, there was a
454 significant linear trend with larger separations resulting in a longer delay on average before saccade
455 initiation for both tasks (slope: STT, 0.21 ± 0.10 ; $p < 0.001$; $t(7) = 5.89$; STM, 0.31 ± 0.18 ; $p < 0.002$; $t(7)$
456 $= 4.96$) as shown in figure 3A. This trend was not accompanied by changes in the intercept of the
457 linear fit (STT = -2.65 ± 4.84 ; $p = 0.17$; $t(7) = 1.55$; STM = -6.03 ± 7.65 ; $p = 0.61$; $t(7) = 2.23$).

458 There were no significant differences between either the slope (figure 3B; $p = 0.21$; $t(7) = 1.38$)
459 or the intercept (-3.38 ± 12.17 ; $p = 0.46$; $t(7) = 0.78$) of the linear regression parameters across the
460 different tasks. This suggests that the size of the remote distractor effect depended on the
461 separation between the two stimuli, regardless of the participant's task and status of the additional
462 stimulus as a distractor. Finally, there was a significant mean correlation between participants'
463 latency on the STT task and their latency on the STM task ($r = 0.76 \pm 0.23$; $p < 0.001$; $t(7) = 9.23$) with
464 on average 58% of the variance in saccade latency shared between the two tasks (figure 3C).

465

466 **Mouse responses**

467 For all the different target-distractor separations the mouse responses were exceptionally
468 accurate for both tasks. Indeed, $94.5 \pm 9.7\%$ of mouse responses were directed towards the task goal
469 (i.e. within $\pm 25\%$ of the separation, corresponding to $0 \pm 15^\circ$ for a 60° separation in the STT
470 task). In contrast, only $55.9 \pm 19.2\%$ of saccades were on average directed towards the task goal, by
471 this same criterion. Even though more rapidly initiated saccades resulted in participants seeing the
472 stimuli for less time before the eye-movement, there were no notable correlations between
473 accuracy in the perceptual task and saccade latency ($p > 0.05$). This suggests that even the most
474 rapidly initiated saccades allowed for sufficient visual processing for participants to correctly locate
475 the goal location.

476

477 **Saccadic landing positions**

478 We quantified the accuracy of saccadic eye-movements by examining the distribution of
479 saccade landing positions relative to the target (red), distractor (blue), intermediate (green) and goal
480 location (orange) for each target-distractor separation (figure 4). The histograms were constructed
481 by sorting the data into 7.5° wide bins, which ensured that even at the smallest tested separation

482 there was one bin in-between the target and distractor. Clear differences can be seen between the
483 saccadic landing position for the two tasks at all the different target-distractor separations
484 examined. Specifically, in the STT task (where the goal location was the target stimulus) there were
485 substantially more saccades directed towards the stimulus assigned as the target than in the STM
486 task (where the task goal was the intermediate location). Thus, participants successfully adjusted the
487 their eye-movements depending on the task requirements. As the close distances between the
488 stimuli makes it difficult to discern by inspection the differences between averaging saccades and
489 saccades directed towards either the target or distractor stimulus, we fit the distributions with a
490 probabilistic mixture model to allow us to estimate the probability of targeting each of these
491 different locations.

492 << FIGURE 4 ABOUT HERE >>

493

494 **Model fitting**

495 We fit both the full model and simpler alternatives (global-effect-only; stimulus-capture-only)
496 to each participant's data. To determine which model provided the best fit, we then contrasted the
497 AICc (Akaike Information Criterion with correction for finite data) of each of these models with that
498 of the full model. This allowed us to determine which components were necessary to capture the
499 saccade landing distribution. Overall, the full model provided the best description of the data when
500 comparing across all target-distractor separations and both tasks ($\Delta AICc \pm SEM$ relative to full model;
501 stimulus-capture-only = 905 ± 117 ; global-effect-only = 813 ± 162). Indeed, even when looking at the
502 sum of AICc across separations within each task separately, the full model was still the better
503 description for both the STT (stimulus-capture-only = 285 ± 51 ; global-effect-only = 709 ± 149 ; figure
504 5A) and STM (stimulus-capture-only = 621 ± 72 ; global-effect-only = 104 ± 16 ; figure 5C) task. In
505 general, as target-distractor separation increased, both alternative models became increasingly poor
506 fits to the data. However, our results indicate that both stimulus capture and global effect
507 components were critical even for the smallest target-distractor separations.

508 The weights of each of the components provided an estimate of the proportion of saccades
509 directed towards that location. The average fits to each of the different target-distractor separations
510 are overlaid in purple in figure 4 for both tasks. The associated weights for the target, distractor, and
511 intermediate components at the different target-distractor separations for the full model are shown
512 in figure 5B and 5D for the STT and STM task respectively. Here we found that the highest weighted
513 component was the one situated at the task goal location for both the STT (goal = $66.5\% \pm 11.2\%$;
514 other = $33.5\% \pm 11.2\%$) and STM (goal = $76.0\% \pm 14.0\%$; other = $24.0\% \pm 14.0\%$) tasks. In the STT task,
515 when averaging across separations, most saccades were directed towards the target location

516 (67%±11%). Only a small proportion of saccades were captured towards the distractor location
517 (9%±4%), with the remainder targeting the intermediate location (25%±13%).

518 Supporting previous findings, we found that the likelihood of executing a saccade towards the
519 global effect location in the STT task decreased as the separation between the target and distractor
520 stimulus increased (slope = -0.50%±0.46% per degree; $p = 0.017$; $t(7) = 3.12$), while the weight for
521 the target component increased (slope = 0.47%±0.4% per degree; $p = 0.013$; $t(7) = 3.29$). Across
522 different target-distractor separations the distractor weight remained unchanged (slope =
523 0.03%±0.10% per degree; $p = 0.356$; $t(7) = 0.99$). Importantly, despite the reduction in the weight of
524 the intermediate component as separation increased, even at 75° separation there was evidence for
525 the global effect (9.1%±2.5%; $p = 0.008$; $t(7) = 3.65$). This suggests that even at this large separation,
526 a significant proportion of saccades were still captured to the global effect location.

527 In the STM task we found that most saccades were accurately directed towards the
528 intermediate location (76%±14%), with only a small component weight associated with the stimulus
529 locations (12%±7% average at each location). This demonstrates that participants could alter
530 targeting of their eye-movements in response to the task requirements, and had no difficulty in
531 deliberately targeting the empty space between the two stimuli.

532 While the intermediate (STT vs STM; $p < 0.001$; $t(7) = 8.48$) and target (STT vs STM; $p < 0.001$;
533 $t(7) = 9.05$) components differed substantially between the two tasks, the distractor component
534 (which was never the goal location) remained consistent (STT vs STM; $p = 0.56$; $t(7) = 0.61$). This
535 suggests that while task instructions influenced the probability of saccades landing at the task
536 location, the proportion of saccades which were unavoidably captured by the distractor location did
537 not differ between the two tasks.

538 << FIGURE 5 ABOUT HERE >>

539

540 **Model fitting across time**

541 As the prevalence of the global effect is known to decrease as saccade latency increases, and
542 saccade latency itself is known to increase as target-distractor separation increases, it was important
543 to also analyze the results as a function of saccade latency. We binned the data into 30 ms
544 overlapping bins (with each bin separated by 10 ms) and fit each of our model variants
545 independently to each time-bin. This allowed us to examine how both the weights and the widths of
546 the components within the mixture model changed as saccade latency increased (figure 6). At the
547 individual level, we eliminated time bins that contained less than 15 trials, while at the group level
548 we eliminated the bins in which less than 50% of participants had sufficient trials to be included.

549 The change in AICc scores for the different models as a function of saccade latency are shown
550 in figure 6, with the best fitting model at each time bin denoted by the solid bar under the curve.

551 Here we again found that, across both tasks and for all target-distractor separations, the full model
552 was on average the best fitting model (Δ AIC relative to full model; stimulus-capture-only = 24.7 ± 3.8 ;
553 global-effect-only = 24.4 ± 5.7). Even when looking at the average change in AICc for either the STT
554 (stimulus-capture-only = 15.7 ± 3.4 ; global-effect-only = 41.7 ± 12.4) or the STM (stimulus-capture-only
555 = 32.6 ± 5.4 ; global-effect-only = 5.6 ± 2.5) task separately, the full model fit the data significantly
556 better than the alternatives. Although for some specific time bins there are exceptions where the
557 global-effect-only models provided a marginally better fit, these predominantly occurred only for
558 very long latency saccades in the STM condition (i.e. when almost all saccades were correctly
559 targeting the intermediate (goal) location). Overall it is clear that distinct target, distractor, and
560 averaging components were necessary to accurately account for how saccade landing positions
561 change with saccade latency.

562

<< FIGURE 6 ABOUT HERE >>

563 The changes in the weights for the model found to provide the best fit, the full model, are
564 shown in figure 7 for the different target-distractor separations in the STT (A) and STM (B) tasks. The
565 probability of making an eye-movement that terminated at the goal location (red lines in A, green
566 lines in B) approached 100% as saccade latency increased. While for each target-distractor
567 separation there was substantial capture towards the goal locations for short-latency-saccades (STT:
568 $55.2\% \pm 9.4\%$; STM: $60.1\% \pm 17.5\%$) for all separations (first 30 ms of data, see Methods; STT, all
569 separations; all $p < 0.0019$; all $t(7) > 4.82$; STM, all separations; all $p < 0.0019$; all $t(7) > 4.85$), as
570 saccade latency increased the proportion of saccades directed towards the goal location significantly
571 increased for all separations for both the STT task (slope = $0.38\% \pm 0.19\%$; $p < 0.0008$; $t(7) = 5.64$) and
572 the STM task (slope = $0.23\% \pm 0.11\%$; $p < 0.0005$; $t(7) = 5.36$).

573 Had there been no influence of task on the most rapidly executed saccades, then we would
574 have expected identical weights at low latencies between the two tasks for the same target-
575 distractor separation. Instead we found significant differences between the tasks for short-latency-
576 saccades for the target (STT vs STM; $p < 0.001$; $t(7) = 5.71$) and intermediate weights (STT vs STM; p
577 < 0.002 ; $t(7) = 4.96$). In contrast, the weight of the distractor component did not significantly vary for
578 any of the separations (STT vs STM; $p = 0.537$; $t(7) = 0.65$). These average differences held also for
579 each individual separation, apart from the 15° target-distractor separation in which neither target
580 (STT vs STM; $p = 0.080$; $t(7) = 2.04$), intermediate (STT vs STM; $p = 0.339$; $t(7) = 1.03$), nor distractor
581 (STT vs STM; $p = 0.059$; $t(7) = 2.25$) weights varied. This is probably because, at the smallest
582 separation, the components were difficult to separate given the limited trials available once binned
583 across time. Nevertheless, these results show that even the most rapidly executed saccades
584 displayed a systematic bias in their landing position towards the task goal.

585

<< FIGURE 7 ABOUT HERE >>

586

587 **Dissociating automatic capture from intentional task-related targeting**

588 By comparing each of the different weights across the two tasks, we can differentiate
589 between changes in the probability of executing an automatic saccade towards a stimulus or the
590 intermediate location (automatic capture) and the influence of the task (intentional and goal-
591 directed). We performed this operation at each time-bin for each of the target-distractor
592 separations examined. This allowed us to derive the time-course of interactions between
593 compulsory capture and intentional goal-related activity. The results are shown in in figure 8, where
594 the proportion of saccades which are intentionally directed towards the task goal (orange) are
595 estimated independently of those that are unavoidably captured towards either of the stimulus
596 locations (purple; stimulus capture) or the average location (green; global effect).

597 << **FIGURE 8 ABOUT HERE** >>

598 We found that, apart from the smallest 15° target-distractor separation, in which weights
599 were less clearly differentiated, the task goal had an influence on the probability of targeting
600 different locations even for short-latency saccades (goal weight 30-75° separation: 36.0%±4.0%; all p
601 < 0.0034; all t(7) > 4.33). Additionally, for all separations, the influence of the task was found to
602 significantly increase for saccades initiated later in time (slope = 0.54%±0.14%; p < 0.0001; t(7) =
603 10.68). As the task influence increased, the relative proportion of saccades automatically captured
604 towards either of the stimulus locations (slope = -0.25%±0.12%; p < 0.0006; t(7) = 5.86) or towards
605 the average location (slope = -0.29%±0.12%; p < 0.0003; t(7) = 6.66) decreased. This supports the
606 idea that longer delays before executing saccades result in increased top-down influence on the
607 targeting of the saccade. Furthermore, the initial capture towards the global location for rapidly
608 executed saccades decreased as target-distractor separation increased (slope per degree of
609 separation = -0.55%±0.44%; p < 0.010; t(7) = 3.48). Again, this was even more apparent if the
610 smallest 15° target-distractor separation was excluded (slope = -0.80%±0.49%; p = 0.002; t(7) =
611 4.67).

612 Nonetheless, for all target-distractor separations there was a significant global effect
613 component for short-latency saccades (mean global = 30.5%±14.4%; all p < 0.020; t(7) > 2.98).
614 Similarly, we observed a significant proportion of unavoidable capture towards the stimulus
615 locations at all separations (mean stim = 38.9%±17.0%; all p < 0.004; t(7) > 4.12), with the proportion
616 increasing as the separations increased beyond 30° (slope = 0.91%±0.29%; p < 0.0001; t(7) = 8.82).
617 Despite these changes, the initial strength of the task-related goal component did not appear to
618 change as the separation increased above 30° (slope = -0.10%±0.56%; p = 0.613; t(7) = 0.53). These
619 results suggest that the strength of capture towards either the stimulus or average location is

620 dependent on the separation, while the initial strength of the goal is relatively invariant to the
621 spatial separation of the stimuli.

622

623 **3. Experiment 2**

624 In the second experiment, we investigated the influence of stimulus salience on the
625 interactions between unavoidable capture (to either the stimuli or the global effect location) and
626 intentional goal-directed targeting. We manipulated stimulus saliency by varying the contrast of the
627 noise patch contained within the two stimuli. While we hypothesized that the saliency of the stimuli
628 should influence the speed of saccade initiation, with faster saccades executed towards stimuli with
629 a higher contrast, it was not clear whether higher contrast would affect the proportion of capture
630 towards the stimuli and the global effect location equally. For example, higher contrast may
631 disproportionately increase the likelihood of capture towards the stimulus locations, as their signal
632 strength becomes stronger relative to the background, but this change may occur without increasing
633 the strength of the averaging location.

634

635 **3.1. Methods**

636

637 **Participants**

638 An additional eight naive individuals (19–28 years old; 1 male) took part in Experiment 2. All
639 participants had normal or corrected-to-normal visual acuity and none of them had participated in
640 the previous experiment. Informed consent was obtained prior to the study in accordance with the
641 guidelines of the Helsinki Declaration.

642

643 **Stimuli and procedure**

644 The experiment proceeded identically to Experiment 1, except for the following modifications.
645 We varied the contrast of the stimuli within 5 levels (11%, 19%, 33%, 56%, 95% Michelson contrast).
646 As our posterized noise consisted of 3 distinct tones (a light, mid, and dark tone) we changed the
647 contrast by varying the range between the light and dark tone located within each stimulus (while
648 the mid tone remained the same grey as the background). As in the first experiment we tested both
649 the STT and the STM task, however we did not include the single target condition within the STT task
650 as in Experiment 1. Instead of examining a large range of target-distractor separations, we examined
651 only separations of 30° and 60°. Finally, in Experiment 2 the irrelevant color cue at fixation in the
652 STM task was changed to a completely different color which did not match either stimulus. While

653 this means the two tasks were not completely identical (as in Experiment 1), it was done to preclude
654 the possibility of the color at fixation biasing participants towards the matching-color target stimulus
655 during the STM task and to enable us to rule out any role of the fixation color on our results.

656

657 **Data pre-processing**

658 Eye-movement data was additionally analyzed offline as in Experiment 1. Excluding the trials
659 already detected by online analysis, after offline filtering we were left with an average of 672 trials
660 (96%) in the STM task and 665 trials (95%) in the STT task. This meant that each condition for each
661 participant had approximately 67 trials available for analysis (and 335 when collapsed across
662 contrast).

663

664 **3.2. Results**

665

666 **Saccade latency**

667 The differences in saccade latency (relative to the median latency at 33% contrast across
668 both tasks) are shown in figure 9A. As can be seen for both 30° and 60° separations, there was a
669 substantial decrease in saccade latency as the contrast increased occurring in both tasks. The rate of
670 change in relative saccadic latency as a function of the log contrast was significantly different from
671 zero for both the STT (30°: $p = 0.031$; $t(7) = 2.69$; 60°: $p = 0.007$; $t(7) = 3.80$) and STM (30°: $p < 0.001$;
672 $t(7) = 8.25$; 60°: $p = 0.003$; $t(7) = 4.53$) tasks. While the decrease in latency as contrast increased
673 differed significantly between tasks at 30° (STT vs STM; $p = 0.042$; $t(7) = 2.49$), there was no
674 difference in the slope at 60° (STT vs STM; $p = 0.267$; $t(7) = 1.21$). When combining data across
675 contrasts, there was a significant difference between 30° and 60° target-distractor separations for
676 both the STT ($p < 0.001$; $t(7) = 6.67$) and STM ($p < 0.001$; $t(7) = 6.32$) task. However, there were no
677 differences between the two tasks in the median saccade latency for either 30° ($p < 0.216$; $t(7) =$
678 1.36) or 60° ($p < 0.207$; $t(7) = 1.39$) separations. Additionally, there were no differences in the
679 average median reaction time between subjects in either the 30° or 60° separations of Experiment 1
680 and the same separations with equivalent contrast in experiment 2 (i.e. Experiment 1 (30°) vs
681 Experiment 2 (30°; 0.33% contrast)) for either the STT (30°: $p = 0.143$; $t(7) = 1.65$; 60°: $p = 0.135$; $t(7)$
682 $= 1.69$) or STM (30°: $p = 0.367$; $t(7) = 0.96$; 60°: $p = 0.415$; $t(7) = 0.87$) task.

683

<< FIGURE 9 ABOUT HERE >>

684

685 **Mouse responses**

686 As in Experiment 1, in both tasks the mouse responses were highly accurate across the
687 different target-distractor separations. We found that $94.5 \pm 9.7\%$ (mean \pm SE) of the mouse
688 responses were directed towards the task goal (i.e. within $\pm 25\%$ of the separation), compared to
689 only $55.9 \pm 19.2\%$ of the saccades. We again found no significant correlation between accuracy in the
690 perceptual task and saccade latency ($p > 0.05$).

691

692 **Model fitting across time**

693 We fit the time-course of the data with all three variations of the model both separated and
694 collapsed by stimulus contrast for the STT (figure 7C) and STM (figure 7D) task. Across the different
695 stimulus contrasts we observed little consistent differences in the weights. To test whether the time
696 courses of the weights differed as contrast changed, we fit the changes in the target, distractor and
697 intermediate weights as saccade latency increased for each participant. We could then examine for
698 each participant whether there was a linear trend in either the slope or intercept of the time course
699 changes as the contrast changed. We found that for the 30° target-distractor separation there were
700 no consistent changes in the slope of the weights as contrast changed for either the STT (all $p >$
701 0.123 , all $t(7) < 1.75$) or STM (all $p > 0.193$, all $t(7) < 1.44$) task. For the 60° target-distractor
702 separation there were no changes for the STT task (all $p > 0.193$; all $t(7) < 1.44$), while in the STM
703 task there was a significant decrease in the intermediate weight as contrast increased (Mean \pm SD; -
704 $0.06\% \pm 0.06$; $p = 0.021$; $t(7) = 2.98$) and no change for the target ($0.00\% \pm 0.09$; $p = 0.901$; $t(7) = 0.13$)
705 or distractor ($0.06\% \pm 0.09$; $p = 0.114$; $t(7) = 1.81$) weights. Thus, across the different separations and
706 model components, there were no consistent changes in the time-course as the contrast of the
707 stimuli changed. Instead, the main effect of decreasing stimulus contrast appeared to be a
708 modulation in the time of saccade onset without substantial influences on the underlying dynamics.
709 This meant that although low contrast trials had a smaller proportion of rapid onset saccades than
710 high contrast trials, for a given saccade latency individuals had largely similar weights for each of the
711 different model components. Due to this lack of differences in the weights across time we collapsed
712 the different contrast data together for the remainder of the analysis, benefiting from both the
713 overall increase in the number of trials and from the fact that contrast differences resulted in
714 saccade onset being spread across a greater range of latencies (which increased the overlap in
715 saccade initiation between participants).

716 The full model provided the best description of the data across the different target-
717 distractor separations for both the STT (ΔAIC relative to full model; stimulus-capture-only =
718 33.6 ± 12.0 ; global-effect-only = 88.9 ± 27.1) and STM task (stimulus-capture-only = 97.3 ± 49.9 ; global-
719 effect-only = 15.9 ± 8.2), as indicated by the small squares at the start of each figure (see 6B and 6D).
720 Thus, as in experiment 1, the full model (with components situated on the target, intermediate and

721 distractor location) was required to best describe the data. Importantly, the weights for each
722 separation, combined across contrast, closely corresponded with the weights found in Experiment 1
723 for equivalent target-distractor separations. Thus, we replicated the weights found in response to
724 rapid-onset saccades as well as the time-course in the second experiment with an additional eight
725 naive participants.

726 We again decomposed the weights into automatic and intentional capture effects. As shown
727 in figure 8B, even for target-distractor separations of 60° there was evidence for the presence of the
728 global effect in short-latency saccades (19.2%±3.9%; $p = 0.002$; $t(7) = 4.98$), although it was notably
729 stronger when the separation was only 30° (59.0%±6.5%; $p < 0.001$; $t(7) = 9.13$). Additionally, the
730 probability of eye-movements being automatically captured towards either the global effect location
731 or the location of either of the visible stimuli traded-off as the separation between the stimuli
732 changed, i.e. closer stimuli generated substantially more averaging (30° vs 60°; 59.0%±6.5 vs
733 19.2%±3.9%; $p = 0.001$; $t(7) = 5.35$) and fewer stimulus-directed saccades (30° vs 60°; 3.9%±2.0% vs
734 33.6%±8.8%; $p = 0.006$; $t(7) = 3.92$) than further separated stimuli regardless of task. However, the
735 time-course of the goal-directed activity was found to be almost identical across the two conditions
736 (30° vs 60°; 37.1%±7.7% vs 47.3%±7.8%; $p = 0.173$; $t(7) = 1.52$), suggesting that the influence of top-
737 down selection emerges with a similar time-course regardless of the separation between the stimuli.
738 Finally, as in Experiment 1, the proportion of saccades directed towards the goal increased as
739 saccade latency increased (slope = 0.19%±0.07%; $p < 0.0001$; $t(7) = 7.62$), while the proportion
740 captured to either the stimulus (slope = -0.05%±0.06%; $p = 0.050$; $t(7) = 2.36$) or global effect
741 location (slope = -0.14%±0.06%; $p = 0.0002$; $t(7) = 6.98$) decreased.

742

743 **4. Discussion**

744 We investigated the influence of spatial separation and behavioral goals on the automatic and
745 intentional control of saccadic eye movements. Specifically, we examined how increasing the
746 distance between two simultaneously appearing stimuli altered both the speed and accuracy with
747 which saccades were made towards a goal location. By explicitly asking participants to move their
748 eyes either towards a specific stimulus or towards the midpoint between two stimuli, we
749 characterized how deliberate goal-related selection interacts with automatic stimulus-driven
750 capture. We found that, regardless of task instructions, the distribution of saccade landing positions
751 was best described as a probabilistic mixture of saccades directed to the target, distractor, and
752 intermediate location. This meant that, even when individuals intended to move their eyes to a
753 certain goal location, their saccades were often automatically re-directed towards another location.

754 We found that increasing stimulus separation had opposite effects on the proportion of
755 saccades captured towards visible stimuli (stimulus capture) and those captured towards the

756 intermediate location in-between stimuli (the global effect). This meant that, as separation
757 increased, the proportion of saccades captured to the global effect location decreased while the
758 proportion captured to the visible stimulus locations increased. However, rather than finding an
759 explicit spatial window in which averaging saccades occurred, our results suggested that the
760 likelihood of observing an averaging saccade continuously decreased as target-distractor separation
761 increased. Yet, even with target-distractor separations as large as 75°, we observed a substantial
762 proportion of global effect saccades at short latencies. Thus, it appears the global effect was present
763 well beyond the proposed 20° spatial window (Walker et al., 1997; Van der Stigchel and Nijboer,
764 2013).

765 There are several reasons why, in contrast to previous studies, we may have been able to
766 observe the presence of the global effect at such large stimulus separations. First, we gave explicit
767 and clear instructions in both of our tasks so that participants knew precisely what was the goal
768 location for their saccades. A less explicit definition of the task goal, either through ambiguous
769 instructions (STA) or having participants make a choice between either stimulus (STE), leaves
770 ambiguity as to the goal location (e.g. De Vries et al., 2016; Silvis and Van der Stigchel, 2014; Van der
771 Stigchel et al., 2012) and makes the discrimination of automatically directed saccades from
772 intentional movements difficult.

773 Second, our probabilistic mixture model analysis allowed us to disambiguate global effect,
774 stimulus capture and intentional task-related saccades. Rather than having a single average landing
775 position measure (e.g. Choi et al., 2016; Van der Stigchel and de Vries, 2015; Walker et al., 1997),
776 which is insensitive to the differences between these components, this approach allowed us to
777 detect averaging saccades even when they were not the most frequent response. It also ensured
778 erroneous saccades to the distractor location were not counted towards the global effect. This is
779 frequently evident in studies using median saccade landing position, where an equal distribution of
780 responses to the target and distraction (with only a tiny fraction of saccades to the intermediate
781 location) can nevertheless result in a median saccade landing position in-between the two
782 distributions. Thus, despite its ubiquitous use in studies of the global effect, the median or mean
783 saccade landing position are a poor metric for quantifying the proportion of averaging saccades.
784 While examinations of distributions (i.e. comparing unimodal and bimodal fits) are an improvement
785 (Van der Stigchel and Nijboer, 2013; Van der Stigchel et al., 2012), decomposing the distributions
786 into their constituent parts creates a much more accurate estimate of saccade targeting behavior
787 (De Vries et al., 2016).

788 Third, by explicitly asking participants to target the intermediate location (STM), we could
789 dissociate automatic capture from task-related selection. This provided a sensitive measure able to
790 capture targeting of the global effect location at large separations. Despite some previous findings of

791 global effect at large spatial separations, there has seemingly been a reluctance to interpret the
792 global effect as occurring over a greater range. One reason for this may be the difficulty it poses to
793 neural models, as a larger spatial region of spatial interaction would call for even more, long-range
794 lateral interactions, something which is already questioned in current models (Christie et al., 2015;
795 Lee and Hall, 2006; Marino et al., 2011). For instance, although van der Stigchel and colleagues
796 (2011) observed a global effect even for far distractors, they interpreted this as distinct from the
797 “traditional” global effect as it occurred for greater separations and was seemingly automatic.
798 Interestingly, they argued that it was the lack of top-down selection in their first experiment that led
799 to this non-traditional automatic global effect, while the presence of top-down selection in their
800 second experiment was what allowed no averaging to be observed. In contrast, we argue that the
801 global effect is a purely bottom-up effect.

802 We found clear evidence for saccades directed to both the intermediate location and the
803 stimulus location at all spatial separations tested. Importantly, this was true even when the task goal
804 aligned with the intermediate location, a condition in which additional processes related to goal
805 selection presumably should only reinforce the intermediate location. Furthermore, the proportion
806 of saccades directed towards the stimuli increased and those to the global effect location declined as
807 stimulus separation increased. This contrasts with Christie et al. (2015) who found that center-of-
808 gravity effects did not change with stimulus separation. Unfortunately, because the priming
809 paradigm of Christie and colleagues (2015) does not permit any meaningful analysis of the saccade
810 landing positions, and the combined analyses of both two- and four-stimulus arrays (and hence the
811 center-of-gravity instead of the intermediate position) makes determining what is the equivalent
812 “global effect location” unclear (i.e. is there an intermediate location between each stimulus or
813 simply a single center-of-gravity activation?), direct comparison with their results is difficult.
814 Nevertheless, while we would also suggest that regions outside of the SC involved in processing of
815 the task likely play a critical role in the predominance of the global effect, we would suggest that
816 spatial separation directly affects the likelihood of automatic, stimulus-driven saccades being
817 directed towards either physical stimulus locations or towards the global effect location.

818 Consistent with Viswanathan and Barton (2013), we propose that motor representations for
819 the individual stimuli compete with that of the intermediate position, with the weightings
820 determined by the target-distractor separation. With increased delay before movement onset, top-
821 down task-related processes continually influence this competition and increasingly bias selection
822 towards the task-relevant location. Thus, the most rapid saccades reveal intermediate stages of this
823 competition, where processes have reached threshold before explicit knowledge of the task has had
824 sufficient time to influence activity. Similarly, although averaging saccades were observed for
825 separations in excess of 35°, in their detailed analyses of the spatial interactions governing the global

826 effect using an STT paradigm van der Stigchel and Nijboer (2013) argued that “a genuine global
827 effect is observed when the endpoint distribution is unimodal with the peak between the two
828 stimuli”. While with this definition they conclude that the global effect is only present less than 35°,
829 they also acknowledge that there is a linear trend in the probability of observing averaging saccades.
830 Based on the present findings, we argue that automatic stimulus-driven capture, to either the
831 stimulus locations themselves or to the average position between them, is present whenever
832 multiple stimuli occur. The distance between the stimuli determines whether, for short-latency
833 saccades, this automatic capture is towards the stimuli themselves or towards the average location.
834 However, this transition is continuous without a defined spatial window. While the specific
835 requirements of the task, as well as the salience of the stimuli and the difficulty in discriminating
836 them, all influence the proportion of observed averaging saccades between different experimental
837 paradigms, when these variables are appropriately controlled, automatic capture, both towards the
838 stimuli and to the global effect location, can be observed for all separations.

839

840 **The role of task instructions on the global effect**

841 In examining the global effect, researchers typically have asked participants to saccade to
842 either of two stimuli (STE; i.e. two target paradigms; De Vries et al., 2016), to saccade to a specific
843 stimulus (STT; i.e. target & distractor paradigms; Walker et al., 1997) or have shown two stimuli and
844 given ambiguous (or non-existent) instructions about the task goal (STA; i.e. ambiguous instruction
845 paradigms; Silvis and Van der Stigchel, 2014). However, each of these methods has certain
846 limitations in interpreting the influence of task on performance. With two target paradigms (STE), it
847 is unclear which of the stimulus locations the subject classified as their intended goal. This means
848 that a researcher cannot discern the difference between saccades that were intentionally directed
849 towards a specific goal location and those that were automatically captured towards one of the
850 stimulus locations. The participant may have intentionally selected one of the object’s locations as
851 their intended movement goal, but nevertheless found that their gaze was captured towards the
852 other location.

853 In experiments with both a target and a distractor stimulus (STT), the proportion of saccades
854 to the distractor can be analyzed to estimate the frequency of unintentional capture towards the
855 distractor location. However, as the goal location and the target location are always identical, the
856 frequency of unavoidable capture towards the target location (which inadvertently happens to be
857 correct) cannot be discerned. Our results suggest that the proportion of unavoidable capture
858 towards the distractor stimulus provides a good approximation for the proportion fortuitously
859 captured towards the target location, which in these cases is also the goal location. This is a clear
860 problem with the most common metric used, median landing position, as unless the data is mirrored

861 around the intermediate location, the proportion of saccades landing at the distractor could
862 substantially shift the median towards the middle of the distribution.

863 In paradigms with ambiguous instructions (STA), these problems are compounded, as
864 different participants, or even the same participant on different trials, may have different inferences
865 as to their required task. In such a situation, when two identical stimuli appear, moving one's eyes to
866 the midpoint (which shifts the fovea closer to both stimuli) is objectively just as valid a strategy as
867 selecting either one of the stimuli. By not giving instructions, it has been argued that top-down
868 influences on saccade targeting are avoided. For example, Silvis and Van der Stigchel (2014) explain
869 that "A unique feature of this paradigm is that participants are generally not instructed to aim for a
870 specific target and are simply told to move their eyes as quickly as possible toward the information
871 that appears on the screen" (page 358). The use of instructions is argued to be unnecessary, as the
872 averaging behavior seen is believed to be the "default" behavior. However, other studies have
873 shown that increasing the predictability of stimulus locations (Aitsebaomo and Bedell, 2000; Coëffé
874 and O'Regan, 1987; He and Kowler, 1989) or increasing the accuracy demands of the task (Findlay
875 and Blythe, 2009; Findlay and Kapoula, 1992) both result in a substantially weaker global effect. This
876 suggests that intentional modulation from the task can indeed influence averaging behavior.

877 A recent study by Heeman and colleagues (2014) explicitly investigated the use of ambiguous
878 instructions by testing a "no instruction" condition (STA), in which participants were simply told to
879 move their eyes "as fast as possible to the stimuli presented" (page 31), as well as a condition with
880 explicit instructions to saccade to a specific target (STT). They found more accurate saccades when
881 explicit instructions were given, even for the most rapidly executed saccades. By providing evidence
882 that even saccades with low latency are biased, this suggests that the perceived task or attentional
883 set of the observer cannot be ignored (Folk and Remington, 1998; Folk et al., 1992, 1994). Thus, the
884 data from tasks utilizing ambiguous instructions likely represents the influence of ambiguous top-
885 down information (which within individual participants may represent different, explicit strategies),
886 as opposed to being absent of top-down information.

887

888 **Time-course of intentional control**

889 In the current study, we developed a modified version of the global effect paradigm that
890 enabled us to separate the influences of incidental capture and intentional, goal-directed targeting.
891 We achieved this by manipulating the task instructions so that, in the different tasks, the movement
892 goal was dissociated from the location of the target stimulus or global effect location. By contrasting
893 the two identical paradigms, varying only in task goal, we could compare the component weights for
894 each participant and dissociate the influence of automatic capture towards visible stimuli from the
895 slower, intentional effects arising from the top-down selection of the task goal. Not only was this the

896 first demonstration of a task explicitly requiring the participant to saccade to the midpoint between
897 two stimuli, but we were also able, from behavioral data alone, to derive the time-course over which
898 goal-related planning influences saccade targeting.

899 We found that the influence of task increased with saccade latency until saccades initiated as
900 late as 300 ms almost all landed accurately at the task goal. However, we also found that there was a
901 non-negligible influence of task on even the fastest initiated saccades. These findings conflict with
902 the conclusions of Heemans et al (2014). These authors argued that, although activity in the superior
903 colliculus represents a combination of both automatic (bottom-up) and intentional (top-down)
904 processes (Bompas and Sumner, 2011; Meeter et al., 2010; Trappenberg et al., 2001), the intentional
905 influences take longer to process when coding saccade targets, leaving the fastest initiated saccades
906 almost entirely exogenously driven. Instead we find a considerable influence of task even for the
907 most rapid saccades.

908 Rather than representing a dynamic response to the stimuli on the current trial, some of this
909 early influence of task may instead represent an anticipatory response to the overarching task
910 demands. For example, when participants are in a block in which they must explicitly saccade to the
911 stimulus that matches the color at fixation, they may prime the relevant feature detectors in
912 anticipation of the stimulus appearing (Folk et al., 1992, 1994; Wu et al., 2014). Conversely, when
913 explicitly required to moving their eyes to the global effect location, participants may be able to pre-
914 emptively boost attention to lower spatial frequencies that are more likely to encompass both
915 stimuli (Ludwig et al., 2007). As such, while our results certainly provide evidence that the task
916 influences even rapid eye-movements, this influence may be more akin to pre-attention filters (Folk
917 et al., 1992) than active selection based solely on visual processing of the stimuli.

918 Nevertheless, these findings give strong support to the idea that the general increase in
919 saccade accuracy for longer latency saccades is due to task-related top-down feedback.
920 Furthermore, they support the suggestion that this time-course is related to the time it takes for
921 task-related signals from higher visual areas (i.e. frontoparietal regions), responsible for selection
922 and decision making, to be propagated back to early visual areas where they can boost the
923 processing of the selected visual stimuli and facilitate targeting the correct location for the upcoming
924 eye-movement (reverse hierarchy theory; Hochstein and Ahissar, 2002). Indeed, the time-course
925 observed in the current experiment corresponds well with a range of different studies investigating
926 visual search, spatial cueing and eye-movements that have suggested attentional selection takes
927 approximately 150-200 ms to reach primary visual cortex (Buffalo et al., 2010; Mehta et al., 2000).
928 Here the demands of the task are critical in determining the delay, as the longer times required to
929 reach decision thresholds for more difficult tasks can substantially alter the speed at which
930 intentional selection influences task performance.

931 This matches well with previous results showing that, while changing the discriminability of
932 the target does not eliminate the biases observed for rapidly executed saccades, it does influence
933 the overall saccade landing distribution, presumably by influencing the time it takes for intentional
934 selection to influence behavior. For more difficult discriminations, intentional selection would be
935 delayed, meaning that while early saccades would still be predominantly influenced by low-level
936 stimulus properties, the improvement from selection would develop more gradually. Interestingly,
937 we observed that the intentional goal-directed influence on saccade targeting appeared to follow
938 the same time-course regardless of separation. As such, the time-course of attentional selection
939 appeared to be unchanged by stimulus separation, which itself does not affect stimulus
940 discriminability. Similarly, while our contrast manipulation altered the saliency of the noise patch
941 within stimuli, it affected both stimuli equally and did not alter the visibility of the colored ring
942 (which was the feature critical in discriminating between target and distractor). Thus, also in
943 Experiment 2 the time-course of intentional selection remained largely similar across contrast
944 conditions.

945

946 **Manipulation of contrast**

947 In Experiment 2 we manipulated the contrast of both the stimuli to see whether this
948 manipulation altered the strength of stimulus capture and/or the global effect. While the overall
949 contrast influenced median saccade latency, with higher contrast stimuli producing more rapid eye-
950 movements, we were not able to discern a differential effect on the probability of making an
951 averaging saccade. However, the results of Experiment 2 not only replicated the findings of
952 Experiment 1 with an additional eight naïve subjects, but allowed us, by collapsing across contrast
953 levels, to generate a substantially smoother and more robust time-course, due to the greater
954 number of trials. Indeed, the close correspondence between results from the two experiments
955 suggests our findings are robust and generalizable to the wider population.

956 Although our contrast manipulation did not differentiate between stimulus capture and the
957 global effect, future experiments could extend our findings by manipulating the contrast of the two
958 stimuli independently and using our method to quantify how stimulus competition affects the
959 likelihood of capture to stimulus or global effect locations. Varying the contrast may bias averaging
960 saccades towards the higher contrast stimuli, resulting in saccades directed not to the intermediate
961 position but somewhere in-between there and the stimulus. Alternatively, the global effect location
962 may be unaffected by the contrast of individual stimuli and instead reflect the center of mass of the
963 two stimuli or the bisected distance between the two, independently of the visibility of each
964 stimulus. It would also be interesting to compare with perceptual judgements of the mid-point
965 between the stimuli, to see if they remain accurate under these circumstances, or if the differences

966 in contrast between the stimuli bias the perceptual midpoint location towards the more salient
967 stimulus.

968 In the first experiment the two tasks were kept as close to identical as possible, with the only
969 difference between the tasks being the verbal instructions. While this ensured that we could ascribe
970 differences in our results to the task itself, it meant that in the STM task participants were also
971 required to ignore the color of the fixation. In Experiment 2, the fixation color was changed to a non-
972 matching color during the STM task. Despite this change, we replicated the results of Experiment 1,
973 suggesting that this color cue played no role in our results. Nevertheless, there was a very slight
974 tendency for the weight of the target stimulus to be slightly larger than the distractor stimulus
975 during the STM task in Experiment 1 (when instead they should be identical – as seen in Experiment
976 2). Future studies could investigate whether task-irrelevant color cueing of one of the stimuli is able
977 to influence the targeting of automatic, stimulus-driven eye-movements and, perhaps more
978 importantly, whether it can also influence the position of the global effect location.

979 **Perceptual judgements**

980 We had participants perceptually localize the goal location after each saccade by indicating its
981 location with the computer mouse. This was an important control to ensure that participants could
982 accurately localize the stimuli on every trial. It also allowed us to examine whether the cases in
983 which participants made non-goal directed eye-movements were associated with changes in the
984 accuracy of perceptual localization. We found no such change in the mouse response accuracy
985 regardless of the accuracy of eye-movements.

986 These results support the work of Eggert and colleagues (2002) who found a global effect in a
987 saccade target task, but failed to find a similar effect for perceptual localization judgements.
988 However, it is important to note that visual information available before the saccade may have
989 benefited from continued processing even after saccade initiation. Thus, although there was
990 sufficient information to accurately localize the goal location by the time of the mouse response, this
991 information may not yet have been available for motor planning at the time of saccade initiation.

992 Despite the inaccuracies in saccade endpoints, evidence from studying attentional shifts
993 (Deubel and Schneider, 1996) has shown that participant's attention is located at the intended
994 target location, irrespective of where the eyes land. This implies that even when sudden onsets or
995 averaging causes the executed saccade to be inaccurate, the target selection remains precise (Van
996 der Stigchel and de Vries, 2015). Given the proposed tight coupling between attention and action
997 (Hoffman and Subramaniam, 1995; Shepherd et al., 1986; Van der Stigchel and Theeuwes, 2005),
998 this suggests that while many factors may contribute to the accuracy of the enacted motor
999 command, target selection is likely to remain tightly focused on the actual saccade target. Previous
1000 work showing that the global effect represents averaging between the saccade goal and distractors

1001 (and not between stimuli per se) provides further evidence as to why the perceptual localization of
1002 the target stimulus might be unaffected (Viswanathan and Barton, 2013). Our results, in which the
1003 intermediate location was equally well localized in the STM task regardless of saccade landing
1004 position, further suggest that the spatial interactions responsible for the errant eye-movements in
1005 global effect tasks are independent from perceived location.

1006 **Conclusions**

1007 We developed a novel paradigm in which task instructions were manipulated to investigate
1008 how intentional target selection interacts with the spatial separation between stimuli. To quantify
1009 these effects, we implemented a probabilistic mixture model which could produce estimates of the
1010 proportion of saccades directed to different locations and how this varied with changes in saccade
1011 latency. By contrasting our model fits across tasks, we could extract the proportion of saccades that
1012 were automatically directed towards the location of visible stimuli or the global effect location, and
1013 distinguish these from the proportion that were intentionally targeted to the goal location. We
1014 found evidence that both visual object capture and the global effect co-occurred at short latencies
1015 for all separations, but their influence declined as latency increased and eye-movements came under
1016 increasing top-down control. Furthermore, we found that as the separation between the stimuli
1017 increased, capture came to dominate the landing positions of fast saccades, with reduced global
1018 effect. Yet even at the largest separations we found evidence for the global effect in rapidly initiated
1019 saccades. Using the mixture model fits we could recreate the time-course over which the
1020 competition between automatic capture and intentional targeting played out. These results
1021 demonstrate a powerful method for extracting the time-course of target selection from eye-
1022 movement data and have importance for our understanding of saccade target selection.

1023

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1026 **References**

- 1027 Aitsebaomo, A.P., and Bedell, H.E. (2000). Saccadic and psychophysical discrimination of double
1028 targets. *Optom. Vis. Sci. Off. Publ. Am. Acad. Optom.* 77, 321–330.
- 1029 Arai, K., McPeck, R.M., and Keller, E.L. (2004). Properties of Saccadic Responses in Monkey When
1030 Multiple Competing Visual Stimuli Are Present. *J. Neurophysiol.* 91, 890–900.
- 1031 Bacon, W.F., and Egeth, H.E. (1994). Overriding stimulus-driven attentional capture. *Percept.*
1032 *Psychophys.* 55, 485–496.
- 1033 Bompas, A., and Sumner, P. (2011). Saccadic Inhibition Reveals the Timing of Automatic and
1034 Voluntary Signals in the Human Brain. *J. Neurosci.* 31, 12501–12512.

- 1035 Boot, W.R., Kramer, A.F., and Peterson, M.S. (2005). Oculomotor consequences of abrupt object
1036 onsets and offsets: Onsets dominate oculomotor capture. *Percept. Psychophys.* *67*, 910–928.
- 1037 Buffalo, E.A., Fries, P., Landman, R., Liang, H., and Desimone, R. (2010). A backward progression of
1038 attentional effects in the ventral stream. *Proc. Natl. Acad. Sci. U. S. A.* *107*, 361–365.
- 1039 Choi, W.Y., Viswanathan, J., and Barton, J.J.S. (2016). The temporal dynamics of the distractor in the
1040 global effect. *Exp. Brain Res.* *234*, 2457–2463.
- 1041 Chou, I., Sommer, M.A., and Schiller, P.H. (1999). Express averaging saccades in monkeys. *Vision Res.*
1042 *39*, 4200–4216.
- 1043 Christie, J., Hilchey, M.D., Mishra, R., and Klein, R.M. (2015). Eye movements are primed toward the
1044 center of multiple stimuli even when the interstimulus distances are too large to generate saccade
1045 averaging. *Exp. Brain Res.* *233*, 1541–1549.
- 1046 Coëffé, C., and O'Regan, J.K. (1987). Reducing the influence of non-target stimuli on saccade
1047 accuracy: Predictability and latency effects. *Vision Res.* *27*, 227–240.
- 1048 Coren, S., and Hoenig, P. (1972). Effect of non-target stimuli upon length of voluntary saccades.
1049 *Percept. Mot. Skills* *34*, 499–508.
- 1050 De Vries, J.P., Van der Stigchel, S., Hooge, I.T.C., and Verstraten, F.A.J. (2016). Revisiting the global
1051 effect and inhibition of return. *Exp. Brain Res.* *234*, 2999–3009.
- 1052 Deubel, H., and Schneider, W.X. (1996). Saccade target selection and object recognition: Evidence for
1053 a common attentional mechanism. *Vision Res.* *36*, 1827–1837.
- 1054 Deubel, H., Wolf, W., and Hauske, G. (1984). The Evaluation of the Oculomotor Error Signal. In
1055 *Advances in Psychology*, A.G.G. and F. Johnson, ed. (North-Holland), pp. 55–62.
- 1056 Dorris, M.C., Olivier, E., and Munoz, D.P. (2007). Competitive Integration of Visual and Preparatory
1057 Signals in the Superior Colliculus during Saccadic Programming. *J. Neurosci.* *27*, 5053–5062.
- 1058 Edelman, J.A., and Keller, E.L. (1998). Dependence on Target Configuration of Express Saccade-
1059 Related Activity in the Primate Superior Colliculus. *J. Neurophysiol.* *80*, 1407–1426.
- 1060 Eggert, T., Sailer, U., Ditterich, J., and Straube, A. (2002). Differential effect of a distractor on primary
1061 saccades and perceptual localization. *Vision Res.* *42*, 2969–2984.
- 1062 Engbert, R., and Mergenthaler, K. (2006). Microsaccades are triggered by low retinal image slip. *Proc.*
1063 *Natl. Acad. Sci. U. S. A.* *103*, 7192–7197.
- 1064 Everling, S., Dorris, M.C., Klein, R.M., and Munoz, D.P. (1999). Role of Primate Superior Colliculus in
1065 Preparation and Execution of Anti-Saccades and Pro-Saccades. *J. Neurosci.* *19*, 2740–2754.
- 1066 Findlay, J.M. (1982). Global visual processing for saccadic eye movements. *Vision Res.* *22*, 1033–
1067 1045.
- 1068 Findlay, J.M., and Blythe, H.I. (2009). Saccade target selection: Do distractors affect saccade
1069 accuracy? *Vision Res.* *49*, 1267–1274.
- 1070 Findlay, J.M., and Kapoula, Z. (1992). Scrutinization, Spatial Attention, and the Spatial Programming
1071 of Saccadic Eye Movements. *Q. J. Exp. Psychol. Sect. A* *45*, 633–647.

- 1072 Findlay, J.M., Brogan, D., and Wenban-Smith, M.G. (1993). The spatial signal for saccadic eye
1073 movements emphasizes visual boundaries. *Percept. Psychophys.* *53*, 633–641.
- 1074 Folk, C.L., and Remington, R. (1998). Selectivity in distraction by irrelevant featural singletons:
1075 evidence for two forms of attentional capture. *J. Exp. Psychol. Hum. Percept. Perform.* *24*, 847–858.
- 1076 Folk, C.L., Remington, R.W., and Johnston, J.C. (1992). Involuntary covert orienting is contingent on
1077 attentional control settings. *J. Exp. Psychol. Hum. Percept. Perform.* *18*, 1030–1044.
- 1078 Folk, C.L., Remington, R.W., and Wright, J.H. (1994). The structure of attentional control: Contingent
1079 attentional capture by apparent motion, abrupt onset, and color. *J. Exp. Psychol. Hum. Percept.*
1080 *Perform.* *20*, 317–329.
- 1081 Franconeri, S.L., Simons, D.J., and Junge, J.A. (2004). Searching for stimulus-driven shifts of attention.
1082 *Psychon. Bull. Rev.* *11*, 876–881.
- 1083 Glimcher, P.W., and Sparks, D.L. (1993). Representation of averaging saccades in the superior
1084 colliculus of the monkey. *Exp. Brain Res.* *95*, 429–435.
- 1085 Godijn, R., and Theeuwes, J. (2002). Programming of endogenous and exogenous saccades: Evidence
1086 for a competitive integration model. *J. Exp. Psychol. Hum. Percept. Perform.* *28*, 1039–1054.
- 1087 He, P.Y., and Kowler, E. (1989). The role of location probability in the programming of saccades:
1088 implications for “center-of-gravity” tendencies. *Vision Res.* *29*, 1165–1181.
- 1089 Heeman, J., Theeuwes, J., and Van der Stigchel, S. (2014). The time course of top-down control on
1090 saccade averaging. *Vision Res.* *100*, 29–37.
- 1091 Hochstein, S., and Ahissar, M. (2002). View from the top: hierarchies and reverse hierarchies in the
1092 visual system. *Neuron* *36*, 791–804.
- 1093 Hoffman, J.E., and Subramaniam, B. (1995). The role of visual attention in saccadic eye movements.
1094 *Percept. Psychophys.* *57*, 787–795.
- 1095 Irwin, D.E., Colcombe, A.M., Kramer, A.F., and Hahn, S. (2000). Attentional and oculomotor capture
1096 by onset, luminance and color singletons. *Vision Res.* *40*, 1443–1458.
- 1097 Isa, T., and Hall, W.C. (2009). Exploring the Superior Colliculus In Vitro. *J. Neurophysiol.* *102*, 2581–
1098 2593.
- 1099 Itti, L., and Koch, C. (2001). Computational modelling of visual attention. *Nat. Rev. Neurosci.* *2*, 194–
1100 203.
- 1101 Jacobs, A.M. (1987). On localization and saccade programming. *Vision Res.* *27*, 1953–1966.
- 1102 Jonides, J., and Yantis, S. (1988). Uniqueness of abrupt visual onset in capturing attention. *Percept.*
1103 *Psychophys.* *43*, 346–354.
- 1104 Lee, P., and Hall, W.C. (2006). An In Vitro Study of Horizontal Connections in the Intermediate Layer
1105 of the Superior Colliculus. *J. Neurosci.* *26*, 4763–4768.
- 1106 Ludwig, C.J.H., and Gilchrist, I.D. (2003). Goal-driven modulation of oculomotor capture. *Percept.*
1107 *Psychophys.* *65*, 1243–1251.
- 1108 Ludwig, C.J.H., Eckstein, M.P., and Beutter, B.R. (2007). Limited flexibility in the filter underlying
1109 saccadic targeting. *Vision Res.* *47*, 280–288.

- 1110 Ludwig, C.J.H., Ranson, A., and Gilchrist, I.D. (2008). Oculomotor capture by transient events: A
1111 comparison of abrupt onsets, offsets, motion, and flicker. *J. Vis.* 8, 11–11.
- 1112 Marino, R.A., Trappenberg, T.P., Dorris, M., and Munoz, D.P. (2011). Spatial Interactions in the
1113 Superior Colliculus Predict Saccade Behavior in a Neural Field Model. *J. Cogn. Neurosci.* 24, 315–336.
- 1114 Marino, R.A., Levy, R., and Munoz, D.P. (2015). Linking express saccade occurrence to stimulus
1115 properties and sensorimotor integration in the superior colliculus. *J. Neurophysiol.* 114, 879–892.
- 1116 McSorley, E., and Findlay, J.M. (2003). Saccade target selection in visual search: Accuracy improves
1117 when more distractors are present. *J. Vis.* 3, 20–20.
- 1118 Meeter, M., Stigchel, S.V. der, and Theeuwes, J. (2010). A competitive integration model of
1119 exogenous and endogenous eye movements. *Biol. Cybern.* 102, 271–291.
- 1120 Mehta, A.D., Ulbert, I., and Schroeder, C.E. (2000). Intermodal selective attention in monkeys. I:
1121 distribution and timing of effects across visual areas. *Cereb. Cortex N. Y. N 1991* 10, 343–358.
- 1122 Opstal, A.J. van, and Gisbergen, J.A.M. van (1990). Role of monkey superior colliculus in saccade
1123 averaging. *Exp. Brain Res.* 79, 143–149.
- 1124 Ottes, F.P., Van, G., and Eggermont, J.J. (1984). Metrics of saccade responses to visual double
1125 stimuli: Two different modes. *Vision Res.* 24, 1169–1179.
- 1126 Ottes, F.P., Van Gisbergen, J.A.M., and Eggermont, J.J. (1985). Latency dependence of colour-based
1127 target vs nontarget discrimination by the saccadic system. *Vision Res.* 25, 849–862.
- 1128 Rizzolatti, G., Riggio, L., Dascola, I., and Umiltá, C. (1987). Reorienting attention across the horizontal
1129 and vertical meridians: evidence in favor of a premotor theory of attention. *Neuropsychologia* 25,
1130 31–40.
- 1131 Serences, J.T., and Yantis, S. (2006). Selective visual attention and perceptual coherence. *Trends*
1132 *Cogn. Sci.* 10, 38–45.
- 1133 Sheliga, B.M., Riggio, L., Craighero, L., and Rizzolatti, G. (1995). Spatial attention-determined
1134 modifications in saccade trajectories. *Neuroreport* 6, 585–588.
- 1135 Shepherd, M., Findlay, J.M., and Hockey, R.J. (1986). The relationship between eye movements and
1136 spatial attention. *Q. J. Exp. Psychol. A* 38, 475–491.
- 1137 Silvis, J.D., and Van der Stigchel, S. (2014). How memory mechanisms are a key component in the
1138 guidance of our eye movements: Evidence from the global effect. *Psychon. Bull. Rev.* 21, 357–362.
- 1139 Theeuwes, J. (1994). Endogenous and Exogenous Control of Visual Selection. *Perception* 23, 429–
1140 440.
- 1141 Theeuwes, J., Kramer, A.F., Hahn, S., and Irwin, D.E. (1998). Our Eyes do Not Always Go Where we
1142 Want Them to Go: Capture of the Eyes by New Objects. *Psychol. Sci.* 9, 379–385.
- 1143 Theeuwes, J., Kramer, A.F., Hahn, S., Irwin, D.E., and Zelinsky, G.J. (1999). Influence of attentional
1144 capture on oculomotor control. *J. Exp. Psychol. Hum. Percept. Perform.* 25, 1595–1608.
- 1145 Tipper, S.P., Howard, L.A., and Jackson, S.R. (1997). Selective Reaching to Grasp: Evidence for
1146 Distractor Interference Effects. *Vis. Cogn.* 4, 1–38.

1147 Trappenberg, T.P., Dorris, M.C., Munoz, D.P., and Klein, R.M. (2001). A model of saccade initiation
1148 based on the competitive integration of exogenous and endogenous signals in the superior
1149 colliculus. *J. Cogn. Neurosci.* *13*, 256–271.

1150 Van der Stigchel, S., and Nijboer, T.C.W. (2011). The global effect: what determines where the eyes
1151 land? *J. Eye Mov. Res.* *4*.

1152 Van der Stigchel, S., and Nijboer, T.C.W. (2013). How global is the global effect? The spatial
1153 characteristics of saccade averaging. *Vision Res.* *84*, 6–15.

1154 Van der Stigchel, S., and Theeuwes, J. (2005). Relation between saccade trajectories and spatial
1155 distractor locations. *Cogn. Brain Res.* *25*, 579–582.

1156 Van der Stigchel, S., and de Vries, J.P. (2015). There is no attentional global effect: Attentional shifts
1157 are independent of the saccade endpoint. *J. Vis.* *15*, 17.

1158 Van der Stigchel, S., Mulckhuysen, M., and Theeuwes, J. (2009). Eye cannot see it: The interference of
1159 subliminal distractors on saccade metrics. *Vision Res.* *49*, 2104–2109.

1160 Van der Stigchel, S., Vries, J.P. de, Bethlehem, R., and Theeuwes, J. (2011). A global effect of capture
1161 saccades. *Exp. Brain Res.* *210*, 57–65.

1162 Van der Stigchel, S., Heeman, J., and Nijboer, T.C.W. (2012). Averaging is not everything: the saccade
1163 global effect weakens with increasing stimulus size. *Vision Res.* *62*, 108–115.

1164 Viswanathan, J., and Barton, J.J.S. (2013). The global effect for antisaccades. *Exp. Brain Res.* *225*,
1165 247–259.

1166 Vitu, F. (2008). About the global effect and the critical role of retinal eccentricity: Implications for eye
1167 movements in reading. *J. Eye Mov. Res.* *2*.

1168 Vitu, F., Lancelin, D., Jean, A., and Farioli, F. (2006). Influence of foveal distractors on saccadic eye
1169 movements: A dead zone for the global effect. *Vision Res.* *46*, 4684–4708.

1170 Walker, R., Deubel, H., Schneider, W.X., and Findlay, J.M. (1997). Effect of Remote Distractors on
1171 Saccade Programming: Evidence for an Extended Fixation Zone. *J. Neurophysiol.* *78*, 1108–1119.

1172 Wu, S.-C., and Remington, R.W. (2003). Characteristics of covert and overt visual orienting: Evidence
1173 from attentional and oculomotor capture. *J. Exp. Psychol. Hum. Percept. Perform.* *29*, 1050–1067.

1174 Wu, S.-C., Remington, R.W., and Folk, C.L. (2014). Onsets do not override top-down goals, but they
1175 are responded to more quickly. *Atten. Percept. Psychophys.* *76*, 649–654.

1176 Yantis, S. (1993). Stimulus-driven attentional capture and attentional control settings. *J. Exp. Psychol.*
1177 *Hum. Percept. Perform.* *19*, 676–681.

1178 van Zoest, W., Donk, M., and Theeuwes, J. (2004). The Role of Stimulus-Driven and Goal-Driven
1179 Control in Saccadic Visual Selection. *J. Exp. Psychol. Hum. Percept. Perform.* *30*, 746–759.

1180 van Zoest, W., Donk, M., and Stigchel, S.V. der (2012). Stimulus-salience and the time-course of
1181 saccade trajectory deviations. *J. Vis.* *12*, 16–16.

1182

1183

1184 **Figure 1. Procedure for the two different tasks.** The procedure for the saccade to target (STT; A) and
1185 saccade to middle (STM; B) tasks are shown. Participants were required to maintain fixation until the
1186 disappearance of the fixation stimulus, at which stage they executed an eye-movement as rapidly as
1187 possible to the task goal location. Immediately afterwards they were required to indicate the goal
1188 location with the computer mouse. They were then given feedback regarding the magnitude (but
1189 not the angle) of their saccade (to discourage participants undershooting the goal location) and the
1190 latency of their saccade (with participants instructed to aim for 200 ms or faster) and were shown
1191 the location of their perceptual response in relation to the target and distractor. A close-up view of
1192 the stimuli, with the different contrast modifications used in Experiment 2, is shown in panel C.

1193

1194 **Figure 2. Probabilistic mixture model.** The data shown in figure 2 shows a histogram of saccade
1195 landing endpoints distributions for fictitious data on the STT task with a target and distractor
1196 separation of 45°. The target, distractor and intermediate locations are shown by red, blue, and
1197 green symbols, respectively, while the task goal (here “saccade to target”) is indicated by the orange
1198 triangle. The general formula for the full model is shown with a diagram of the corresponding
1199 Gaussian distribution shown above each component. The sum of the Gaussians is shown in purple.
1200 Each component consists of a weight, determining its relative strength in the mixture, a fixed
1201 parameter for the Gaussian’s center (target, intermediate or distractor) and a parameter for the
1202 width of the distribution. We additionally examined simpler variations of the model in which we
1203 selectively eliminated different components to test their necessity for accurately describing the data.

1204

1205 **Figure 3. Saccade latency for the different tasks and target-distractor separations.** The changes in
1206 saccade latency between the two tasks as the target-distractor separation increased are shown in
1207 3A. Here saccade latency was expressed as the relative difference between the median saccade
1208 latency at a 15° separation across both tasks per subject, with the data showing the mean
1209 differences with standard error. The shaded region indicates the 95% confidence intervals for a
1210 linear fit. The median saccade latency for each of the subjects on both tasks is shown in figure 3C.
1211 Here a strong correlation between the times in both tasks is evident, demonstrating that the time to
1212 initiate their saccade is closely related in both tasks. Additionally, the trend for larger separations to
1213 have slower saccade latency is evident within individual subjects’ data with the distance from the
1214 origin increasing as target-distractor separation increases.

1215

1216 **Figure 4. Histograms of landing position for different target-distractor separations.** Distributions of
1217 the average landing position across participants for the STT (figure 4A) and STM (figure 4B) task are

1218 shown. Note that the goal location in the STT task was the target location (red), while the goal
1219 location for the STM task was the intermediate location (green). From the histograms above it can
1220 clearly be seen that the simple change of task goal resulted in substantially different distributions for
1221 all the different target-distractor separations, with the effects most noticeable at larger separations.
1222 The purple line indicates the average full model fit to the collapsed data for each subject.

1223

1224 **Figure 5. The AICc of the different model fits and the weights of the best model for different**
1225 **target-distractor separations in the STT and STM tasks.** For both the STT (A) and STM (C) task the
1226 full model, which included a target, distractor, and intermediate component, was always the best fit
1227 to the data (with the lowest change in AICc for each separation indicated by the thick bar beneath).
1228 The weights for the best fitting full model for both STT (B) and STM (D) are also shown.

1229

1230 **Figure 6. The change in AICc across target-distractor separations, task, and experiments as a**
1231 **function of saccade latency.** The average AICc for the different models across participants for
1232 Experiment 1 (A and C) and Experiment 2 (B and D) as a function of saccade latency for the STT and
1233 STM task. While the green line indicates the full model, the yellow and purple lines indicate the
1234 Δ AICc of stimulus-capture-only and global-effect-only models relative to the full model, respectively.
1235 In Experiment 1 the full model almost always fit the data better than either of the alternative
1236 simpler models. Indeed, as the panel collapsed across separations shows, when considering all
1237 target-distractor separations the full model was always the best model (with the small square
1238 indicating the average Δ AICc collapsed across separations and saccade latency). This pattern is true
1239 also for the data of Experiment 2. Here the data collapsed across contrast is presented and, while
1240 the plots are substantially smoother due to the increased number of trials, they match very closely
1241 with the data found in Experiment 1.

1242

1243 **Figure 7. Histograms of landing position for different target-distractor separations.** The mean
1244 weights for the target (red), distractor (blue) and intermediate (green) model components across
1245 participants are shown for each of the different target-distractor separations (columns) and for both
1246 STT (A) and STM (B) tasks. As the latency distributions for individuals varied significantly, above each
1247 set of weights are the proportion of participants with sufficient data for inclusion in the average at
1248 that time-point. Averages of less than 50% of the participants are not shown. The weights for each of
1249 the different contrasts examined in Experiment 2 are shown in figure C and D for STT and STM
1250 respectively, while the weights collapsed across contrast are shown in E and F. Importantly, although

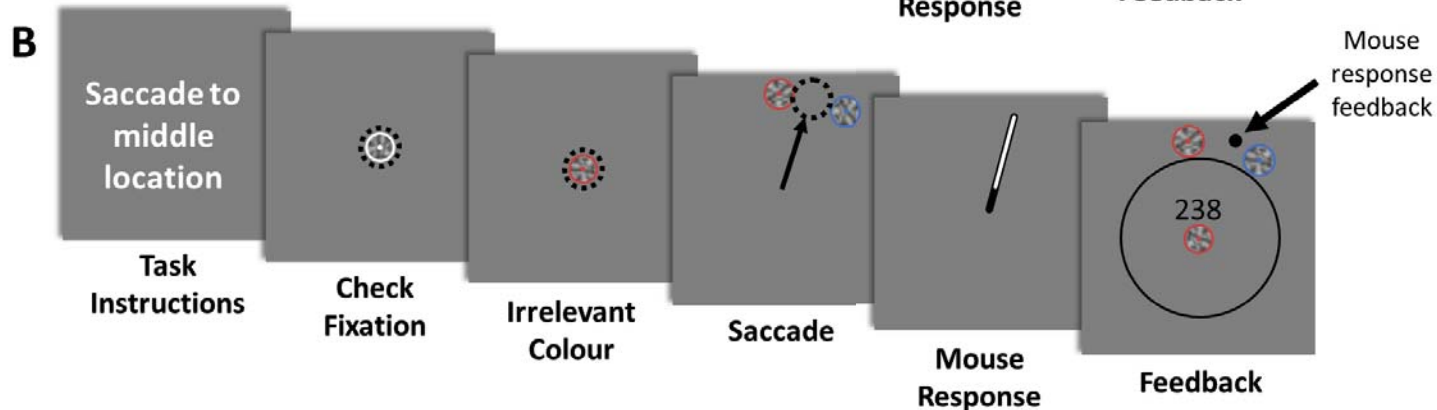
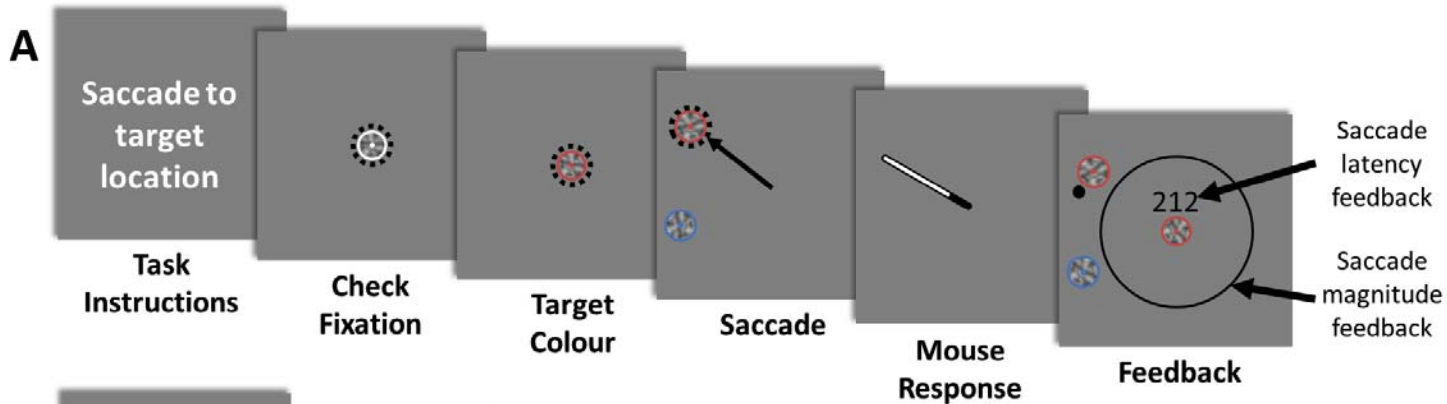
1251 8 new participants were examined, the data for Experiment 2 closely matches the equivalent
1252 separations in Experiment 1.

1253

1254 **Figure 8. Automatic and intentional capture effects in time for different target-distractor**
1255 **separations.** By comparing the STT and STM task for each of the different target-distractor
1256 separations we could generate estimates for the proportion of saccades unavoidably captured
1257 towards either the location of stimuli or the global effect location and those that were intentional
1258 directed towards the task goal for both Experiment 1 (A) and Experiment 2 (B). This reveals how the
1259 proportion of saccades dedicated to different location changes with the delay before movement
1260 onset.

1261

1262 **Figure 9. Saccade latency for 30° and 60° stimulus separation and the influence of stimulus**
1263 **contrast.** A. The relative differences in saccade latency as stimulus contrast increased for both the
1264 STT (red) and STM (green) task for either 30 (left) or 60 (right) degree separation between stimuli. As
1265 contrast increased there was a reduction in the latency of saccades in both tasks, with the reduction
1266 occurring slightly more rapidly in the STM task when stimuli were 30 degrees separated. B. Each
1267 participant's saccade latency for each contrast level (1 = lowest, 5 = highest) on both the STT and
1268 STM task are plotted. Almost all participants show a steady increase in saccade latency as contrast
1269 increases, while the overall latencies for 30° are visibly faster than for 60° (as was found in
1270 Experiment 1).



C Experiment 1



33%

Experiment 2



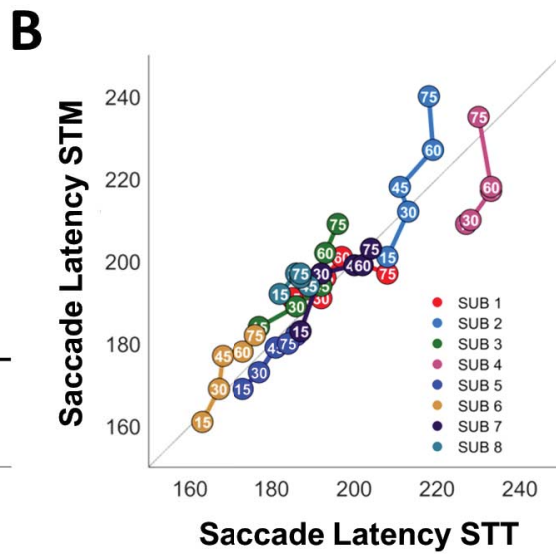
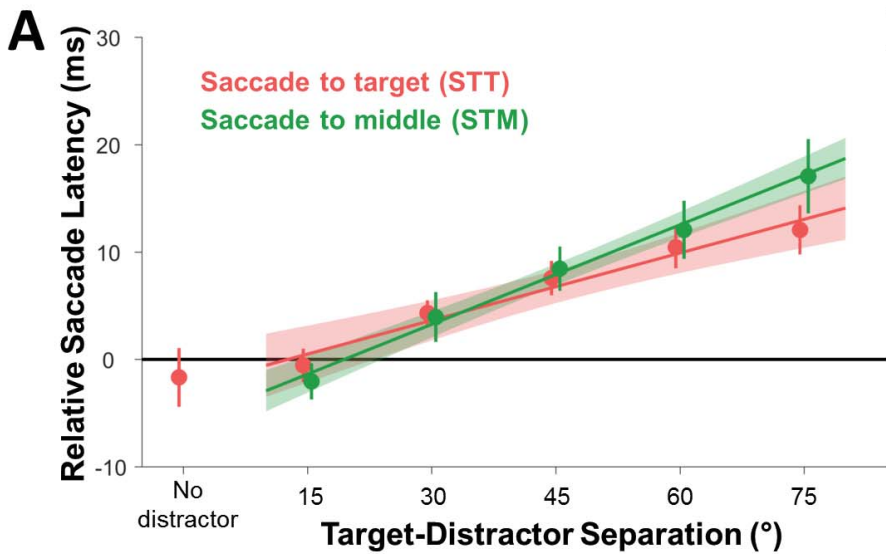
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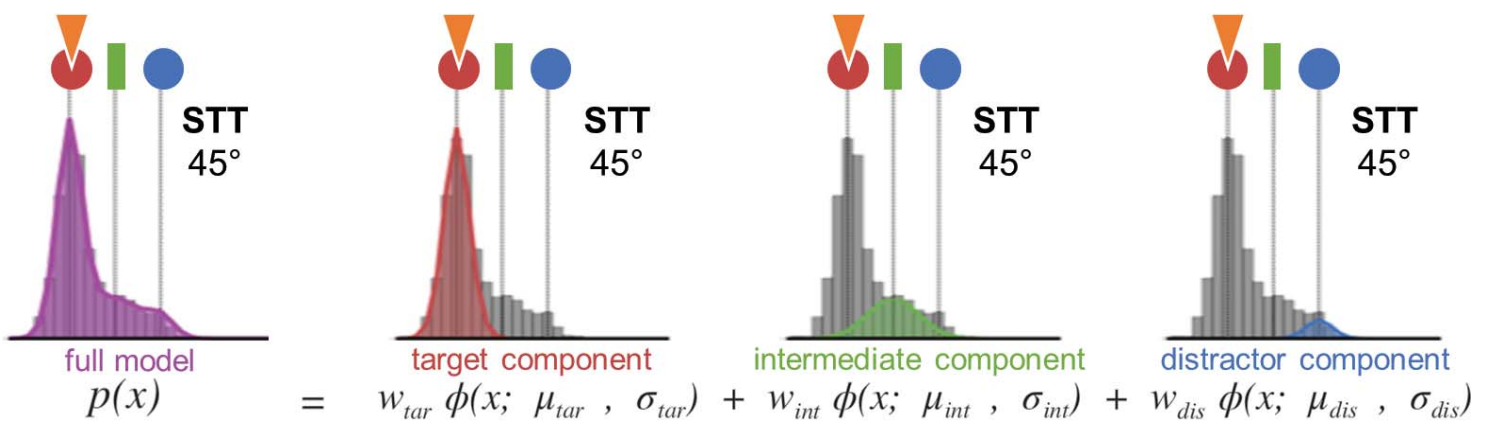
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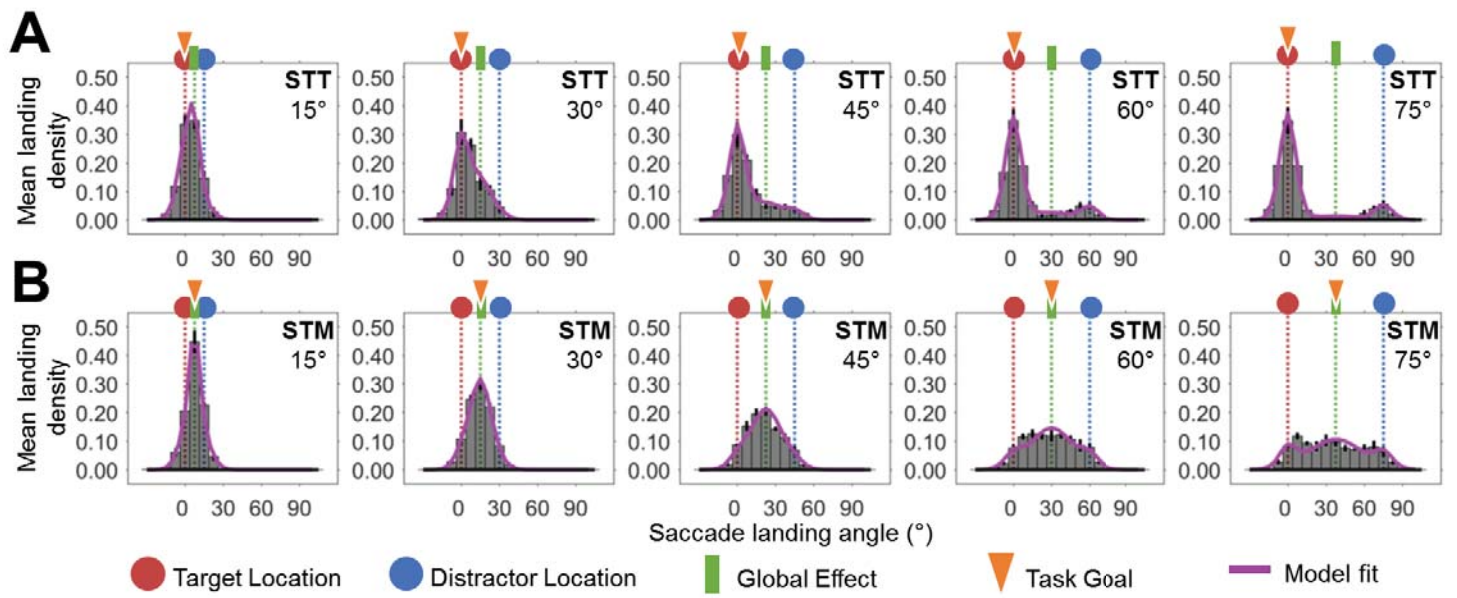
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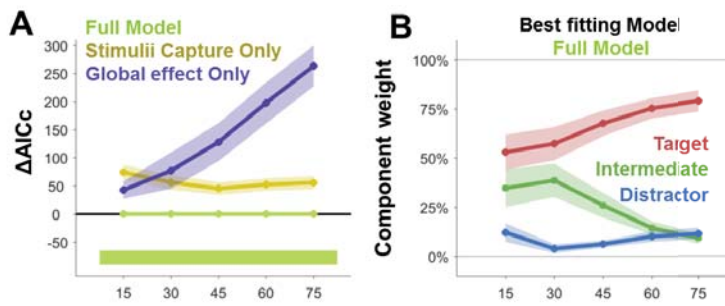
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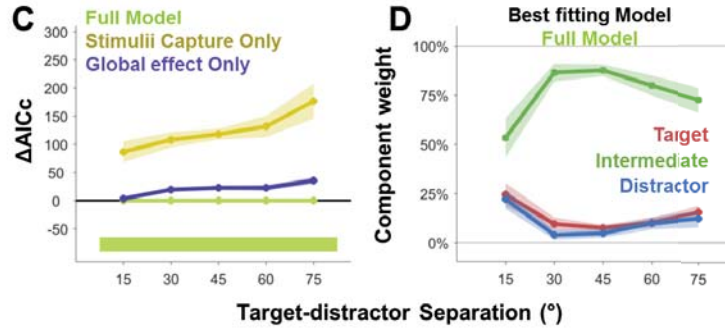




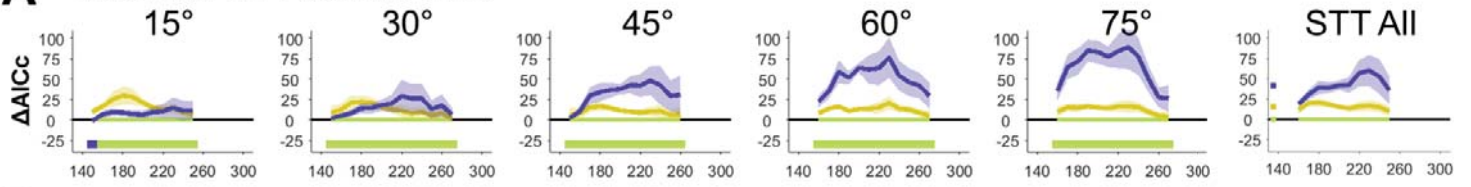
Model fits for saccade to target - STT



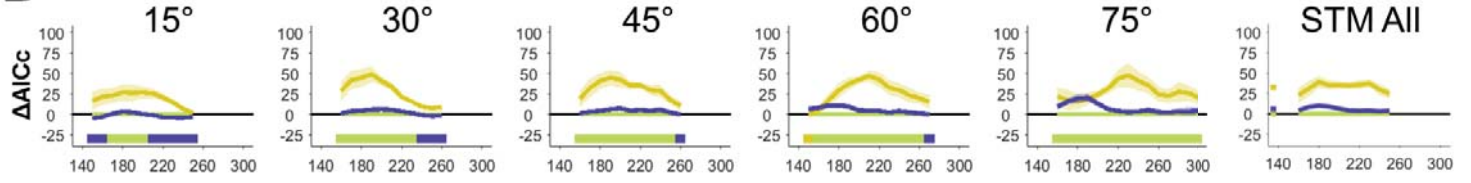
Model fits for saccade to middle - STM



A AICc for STT across time



B AICc for STM across time

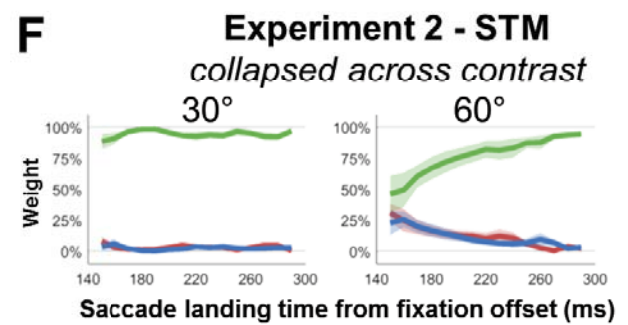
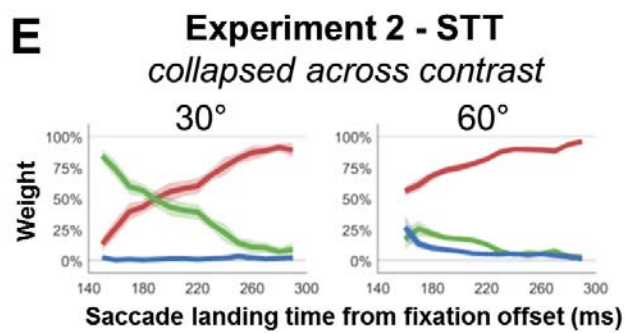
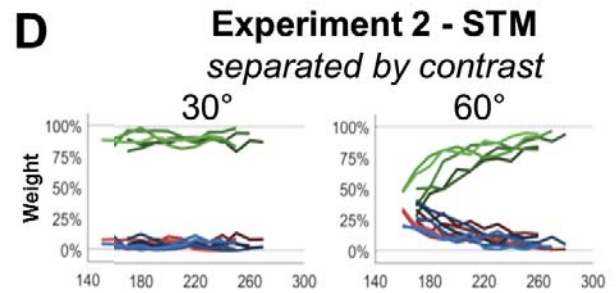
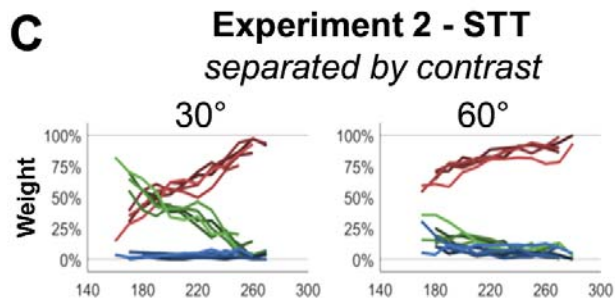
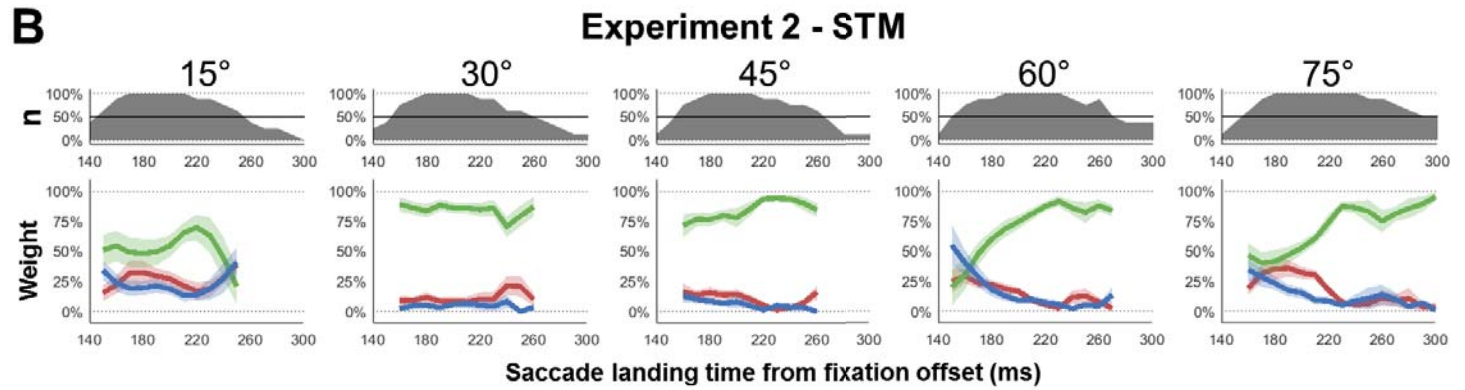
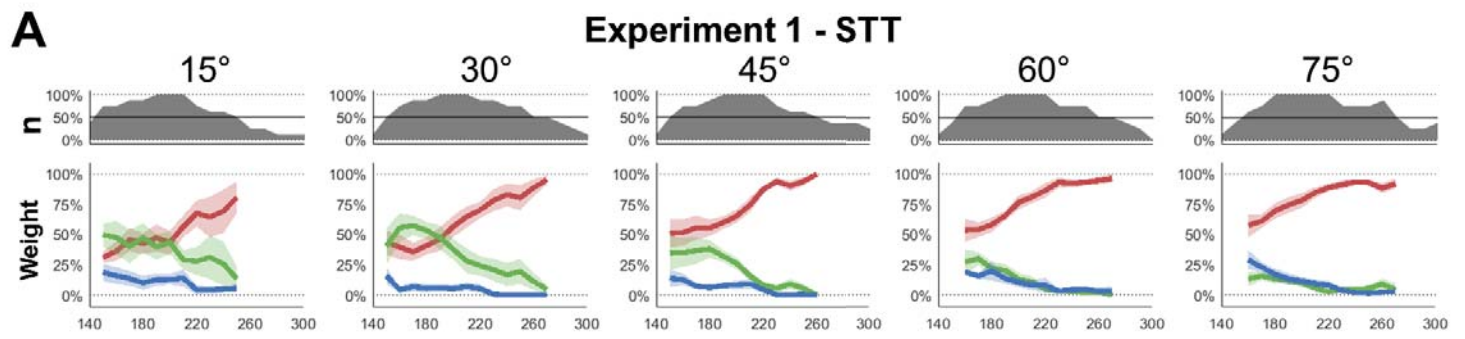


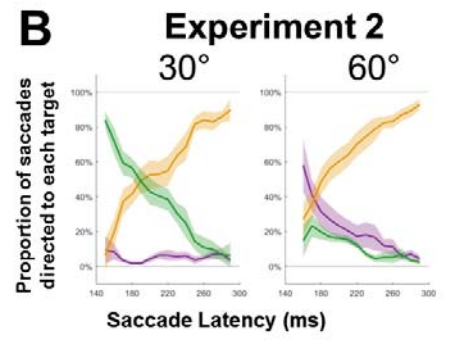
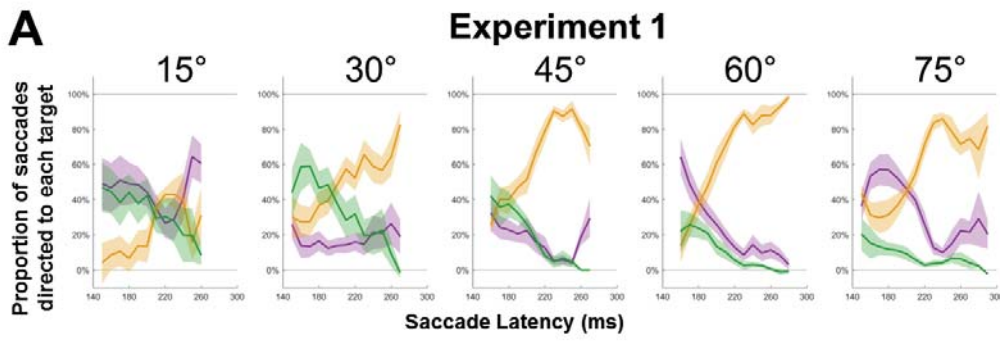
Saccade landing time from fixation offset (ms)

Full: Target + Distractor + Intermediate

Stimulii Capture Only: Target + Distractor

Global effect Only: Intermediate





Automatic Capture: Stimulus Capture, Global Effect

Intentional & Goal-directed: Task Goal

