

1 The effect of offset cues on saccade programming and covert attention

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18 **Abstract**

19 Salient peripheral events trigger fast, 'exogenous' covert orienting. The influential Premotor  
20 Theory of attention argues that covert orienting of attention depends upon planned but unexecuted  
21 eye-movements. One problem with this theory is that salient peripheral events, such as offsets,  
22 appear to summon attention when used to measure covert attention (e.g. the Posner cueing task),  
23 but appear not to elicit oculomotor preparation in tasks that require overt orienting (e.g. the remote  
24 distractor paradigm). Here, we examined the effects of peripheral offsets on covert attention and  
25 saccade preparation. Experiment 1 suggested that transient offsets summoned attention in a  
26 manual detection task without triggering motor preparation planning in a saccadic localisation task,  
27 although there were a high proportion of saccadic capture errors on 'no-target' trials, where a cue  
28 was presented but no target appeared. In Experiment 2 'no-target' trials were removed. Here,  
29 transient offsets produced both attentional facilitation and faster saccadic responses on valid cue  
30 trials. A third experiment showed that the permanent disappearance of an object also elicited  
31 attentional facilitation and faster saccadic reaction times. These experiments demonstrate that  
32 offsets trigger both saccade programming and covert attentional orienting, consistent with the idea  
33 that exogenous, covert orienting is tightly coupled with oculomotor activation. The finding that no-  
34 go trials attenuates oculomotor priming effects offers a way to reconcile the current findings with  
35 previous claims of a dissociation between covert attention and oculomotor control in paradigms that  
36 utilise a high proportion of catch trials (e.g. Klein 1980).

37

38 **Keywords:**

39 Saccade, Oculomotor, Eye-movement, Attention, Cueing, Priming

## 40 Introduction

41 Humans exist in a complex visual environment. Given the limitations on information  
42 processing capacity, a key challenge faced by the visual system is the selection of task-relevant visual  
43 signals from irrelevant noise. One way to achieve this selection is to orient attention to the location  
44 of the relevant signal. Orienting of attention can be driven endogenously, in response to our current  
45 goals (e.g. looking up and down a street before crossing) or exogenously, in response to a salient  
46 event in the environment (e.g. orienting to a flashing light in the rear-view mirror) (Posner & Cohen  
47 1980). Both modes of orienting can occur overtly, by moving the eyes to fixate the relevant location.  
48 However, orienting can also be covert, such that the 'spotlight' of attention is moved while the eyes  
49 remain fixated.

50 Although covert attentional orienting occurs in the absence of overt eye-movements, covert  
51 and overt orienting share some common processes (Awh, Armstrong, & Moore, 2006; Smith &  
52 Schenk, 2012). Indeed, one widely held view is that covert attentional orienting depends on the  
53 activation of the oculomotor system (Klein, 1980; Sheliga, Riggio, & Rizzolatti, 1994). This strong  
54 view of the coupling between attention and eye-movements is controversial and a number of  
55 authors have argued that endogenous covert attention can be deployed in the absence of motor  
56 activation. For example, Klein and colleagues reported that covertly attending a peripheral location  
57 did not facilitate saccadic reaction times (which it should do, if covert attention is the same as motor  
58 preparation; Hunt & Kingstone, 2003; Klein, 1980; Klein & Pontefract, 1994; MacLean, Klein, &  
59 Hilchey, 2015). Similarly, Belopolsky and Theeuwes (2012) have shown that maintenance of  
60 attention is independent of saccade programming, Born et al. (2014) have demonstrated that motor  
61 preparation was not sufficient to orient attention and Dunne, Ellison, and Smith (2015) reported that  
62 instrumental conditioning of eye-movements modulated saccade latencies but not covert orienting  
63 of attention. In related work, we demonstrated that disrupting saccade preparation by presenting  
64 stimuli beyond the range of saccadic eye movements interferes with exogenous orienting to  
65 peripheral onsets, but not endogenous orienting to symbolic cues (Smith, Rorden, & Schenk, 2012)

66 or gaze cues (Morgan, Ball, & Smith, 2014). The same manipulation affects exogenous orienting in  
67 feature search but not endogenous orienting in conjunction search (Smith, Ball, & Ellison, 2014;  
68 Smith, Ball, Ellison, & Schenk, 2010) and encoding and rehearsal of spatial, but not visual working  
69 memories (Ball, Pearson, & Smith, 2013; Pearson, Ball, & Smith, 2014). This pattern of specific  
70 disruption to exogenous attention by disruption to the oculomotor system can also be observed in  
71 clinical populations; patients with oculomotor deficits typically present with defective exogenous  
72 orienting but largely preserved endogenous orienting (Gabay, Henik, & Gradstein, 2010; Rafal,  
73 Posner, Friedman, Inhoff, & Bernstein, 1988; Smith, Rorden, & Jackson, 2004), although see  
74 (Craighero, Carta, & Fadiga, 2001). These studies have led to the proposal that exogenous attention  
75 is tightly coupled to the oculomotor system, whereas endogenous orienting is largely independent of  
76 oculomotor control (Smith & Schenk, 2012).

77         One problem with the conclusion that exogenous orienting is causally linked to motor  
78 preparation comes from the observation that some types of cue can elicit exogenous orienting  
79 seemingly without activating a saccade plan. For example, peripheral offsets reliably summon covert  
80 attention in a Posner-style cueing task (Hopfinger & Mangun, 1998, 2001; Pratt & McAuliffe, 2001;  
81 Riggio, Bello, & Umiltà, 1998) but don't reliably generate a remote distractor effect (Hermens &  
82 Walker, 2010; Todd & Vangelder, 1979), unless the stimuli are defined by contrast rather than colour  
83 (Ludwig, Ranson, & Gilchrist, 2008). Furthermore, the cost of making antisaccades is significantly  
84 reduced if the saccade endpoints are indicated by object offset rather than object onset, suggesting  
85 that onsets exert a much more powerful influence on saccade programming than offsets. (Pratt &  
86 Trottier, 2005). Studies using visual search also indicate that an object offset is less likely to elicit  
87 saccadic programming than an object onset. For example, object disappearances do not elicit  
88 reflexive saccades in visual search (Boot, Kramer, & Peterson, 2005), unless the offset reveals  
89 another object (Brockmole & Henderson 2005). Similarly, short-wavelength colour cues (s-cone  
90 stimuli) do not retard SRTs when used as a distractor in the remote distractor paradigm (RDE),  
91 leading some authors to conclude that they do not elicit activation in the structures critical for the

92 computation of saccade parameters such as the Superior Colliculus. However, the same stimulus  
93 does elicit exogenous shifts of attention (Sumner, Adamjee, & Mollon, 2002). Together, these  
94 studies suggest that some classes of peripheral cues, such as offsets and s-cone stimuli, can reliably  
95 summon covert attention while only producing minimal activation of the oculomotor system.

96         The claim that offsets can reliably capture attention without reliably engaging the  
97 oculomotor system is potentially problematic for theories of attention that propose a mandatory  
98 coupling between the two processes (Klein, 1980; Rizzolatti, Riggio, & Sheliga, 1994; Smith & Schenk,  
99 2012). However, to date no study has explicitly examined the effects of offset cues on exogenous  
100 attentional facilitation and saccade programming within the same study. Here, we address this  
101 question using the Posner cueing task. We operationalised attentional facilitation as faster and more  
102 accurate manual reaction times in covert detection (Experiment 1) and discrimination (Experiments  
103 1, 2 & 3) tasks, and saccade programming as faster and more accurate saccades in a saccadic  
104 localisation task. The claim that offsets can summon attention without triggering saccade  
105 programming leads to a clear prediction; there should be attentional facilitation in the manual  
106 detection and discrimination task, but no facilitation of saccadic reaction time in the saccadic  
107 localisation task.

108

## 109 **General Method**

### 110 ***Participants***

111 Nineteen undergraduate volunteers (14 female, median age 19, 15 right handed); took part in  
112 Experiment 1 and ten other volunteers (5 female, median age 25, 8 right handed) from Durham  
113 University Department of Psychology took part in both Experiment 2 and 3. All participants had  
114 normal vision or wore contact lenses to correct their vision. All participants gave informed consent  
115 to participate. The study was approved by the Department of Psychology Research Ethics Committee  
116 and was conducted in accordance with the BPS code of ethics.

117

**118 Apparatus**

119 Stimuli were generated using a Cambridge Research Systems ViSaGe graphics card and displayed on  
120 a 17-inch Sony Trinitron CRT monitor with a refresh rate of 100 Hz. Manual responses were collected  
121 using a two-button response box. Eye-movements were recorded using a Cambridge Research  
122 Systems Videoeyetracker Toolbox sampling at 250 Hz.

123

**124 Stimuli and general procedure**

125 The placeholders were black squares subtending  $2^\circ$  of visual angle. The fixation point was a  
126  $0.3^\circ$  black spot surrounded by a black square subtending  $2^\circ$ . The peripheral cue was the  
127 disappearance of one of the two peripheral placeholders (Exp1 & 2) or the permanent offset of one  
128 of the peripheral placeholders (Exp3). The central cue was the disappearance of the box  
129 surrounding the fixation point. The target in the Saccadic Localisation and Manual Detection tasks  
130 was a light grey annulus ( $75 \text{ cd/m}^2$ , diameter  $1.5^\circ$ ). In the Discrimination task the target was a filled  
131 white bar ( $100 \text{ cd/m}^2$ ,  $0.5^\circ \times 1.5^\circ$ ). The background was grey ( $54 \text{ cd/m}^2$ ). The viewing distances were  
132 57 cm (Exp1) and 50 cm (Exp2 & 3).

133 The participant was seated on an adjustable chair in a dimly lighted room. After setting up  
134 the eye tracker, a 12 point calibration phase began. If the calibration was unsatisfactory, another  
135 calibration phase was initiated. Otherwise, a block of trials began. Blocks of trials for each condition  
136 were completed consecutively and the order in which the different conditions were presented was  
137 counterbalanced across participants.

138 Response types (Manual Detection (Exp. 1, 2 & 3), Manual Localisation (Exp. 2 &3), Manual  
139 Discrimination (Exp. 2 & 3) or Saccade (Exp. 1, 2 & 3)) were tested in different blocks. Trials began  
140 with the onset on the fixation point and three placeholders. The centres of the peripheral  
141 placeholders were presented at an eccentricity of  $8^\circ$  (Exp.1, 2 &3) or  $10^\circ$  (Exp.1) from fixation in left  
142 and right hemifields. After 1000 ms one of the locations was cued (i.e transient offset or permanent  
143 offset of placeholders) during 100ms. The target was then presented simultaneously with the re-

144 appearance of the placeholder (except for Exp.3) and remained visible until a response was made.

145 Figure 1 illustrates the sequence of events in a typical trial.



146

147 Figure 1: Schematic of a trial from the valid condition illustrating the timing and stimuli used in

148 experiments 1, 2 & 3. Only 1 stimulus eccentricity was used in experiments 2 and 3. The dotted

149 squares on the top panel indicate the 8° eccentricity condition.

150

151 **Analysis**

152 In Experiment 1, one participant withdrew after completing 2 blocks of trials and was  
 153 excluded from the analysis and another participant had False Alarm rates of >33% in the Manual  
 154 Response condition and was also excluded.

155 In the Manual Response condition trials were rejected when (a) blinks, loss of eye tracking or  
 156 other artefacts made it impossible to determine whether a saccade had been executed, (b)  
 157 participants broke fixation in manual condition and (c) had an RT of < 100ms. This resulted in the  
 158 exclusion of ~ 1% of trials in each of the three experiments. In the Saccade condition trials were  
 159 rejected when (a) blinks, loss of eye tracking or other artefacts made it impossible to determine

160 whether a saccade had been executed (1.7% of trials in Exp1, 1.8% in Exp2 and 10.5% in Exp3), (b)  
161 the saccade was made prior to target presentation (3.9% of trials in Exp1, 3.1% in Exp2 and 2.8% in  
162 Exp3) or (c) the saccade was hypometric (less than 2/3rds of the correct amplitude; 0.2% of trials in  
163 Exp1, 2.3% in Exp2 and 0.6% in Exp3). In total, 5.8% of trials were excluded in Experiment 1, 7.2% in  
164 Experiment 2 and 12.5% in Experiment 3.

165

### 166 ***Saccade Identification***

167 Potential saccades were automatically identified offline using velocity criterion of  $\geq 70^\circ/\text{s}$ .  
168 When a potential saccade was identified the algorithm backtracked by 5 samples and recorded this  
169 value. The exact start of the saccade was then found by looking for the first velocity above this  
170 smaller pre-start threshold. The raw signal was unfiltered and the detection algorithm was visually  
171 verified for every trial.

172

### 173 **Experiment 1**

174

#### 175 ***Design***

176 Within each block there were four trial types (1) valid trials where the target appeared at the  
177 cued location, (2) invalid trials where the target appeared contralateral to the cue, (3) Centre cue  
178 trials where the fixation point was cued and the target appeared at one of the two peripheral  
179 locations and (4) Target Absent trials where the cue appeared but there was no target.

180 The cue was the removal of one of the two placeholders for 100ms. In Manual response  
181 blocks participants were instructed to maintain fixation and to indicate target presence as quickly as  
182 possible by pressing the upper button on the response box and the target absence by pressing the  
183 lower button (Target Absent trials). Fixation was monitored by recording eye-movements. In saccade  
184 response blocks participants were instructed to make a saccade as quickly and as accurately as  
185 possible towards the target or to withhold their response in target absent trials. Each participant

186 completed one block of 20 practice trials and 4 blocks of 90 experimental trials (2 manual responses  
 187 and 2 saccade responses). Each block of trials contained 20 valid trials, 20 invalid trials, 20 Centre  
 188 Cue trials and 30 Target Absent trials (10 following a left cue, 10 following a right cue and 10  
 189 following a centre cue). Overall there 22.22% valid trials, 22.22% invalid trials, 22.22% Neutral trials  
 190 and 33.33% Catch trials

191

## 192 **Results**

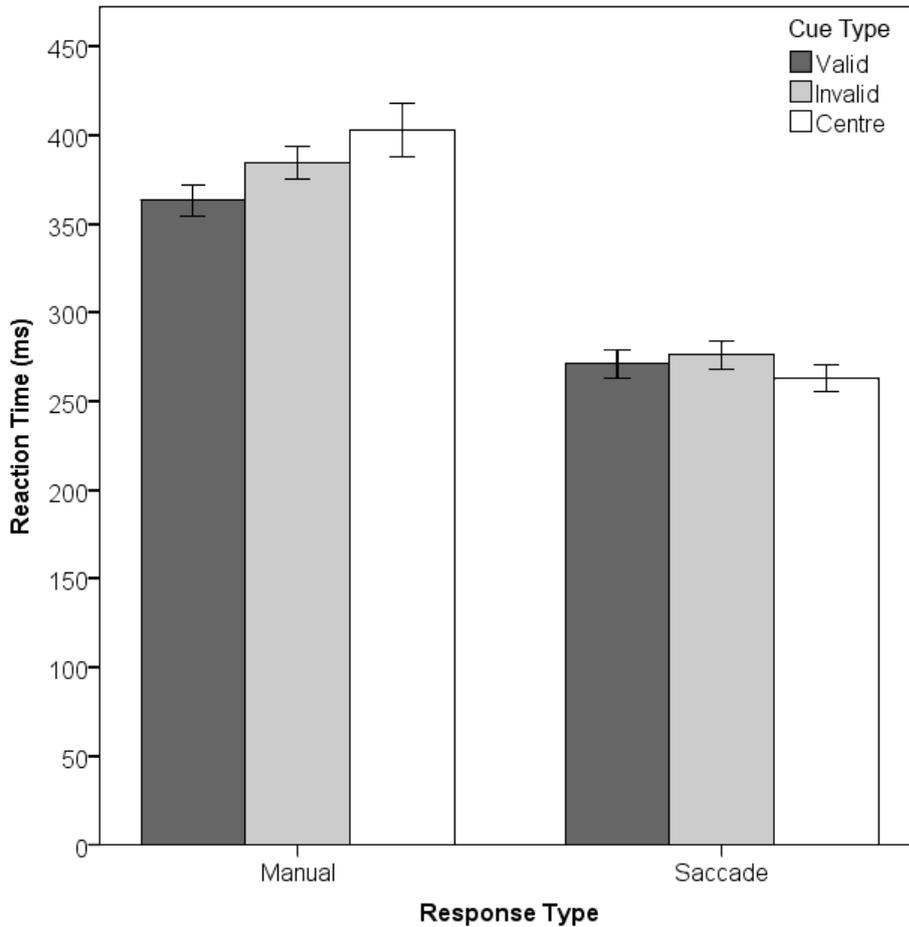
### 193 *Reaction Time*

194 We analysed the reaction time data from correct responses (84% of trials) with a 2 x 2 x 3  
 195 repeated measures ANOVA with factors of Stimulus Eccentricity (8 and 10 degrees), Response Type  
 196 (Manual or Oculomotor) and validity (valid, invalid and central cue). There was no main effect of  
 197 Stimulus Eccentricity ( $F = .203$ ) and no interactions between Eccentricity and any of the other factors  
 198 (all  $F$ 's <1), so we collapsed across Stimulus Eccentricity for the remaining analyses.

199 Reaction time data from correct responses are shown in figure 2. Inspection of figure 2  
 200 suggests the presence of a cueing effect in the manual RT data but not the saccadic RT data. To test  
 201 this potential interaction effect the median (S)RT was calculated for all correct responses for each  
 202 individual. The RTs were then subjected to a 2 x 3 ANOVA with within-subjects factors of Response  
 203 Type (Manual or Oculomotor) and validity (valid, invalid and central cue). The ANOVA revealed a 2-  
 204 way interaction between Response Type and validity ( $F_{(2,32)} = 13.37, p < .05, \eta p^2 = .45$ ).

205 The interaction was explored using ANOVAs with a single factor of validity conducted at each  
 206 level of Response Type. For Manual responses there was a main effect of validity ( $F_{(2,32)} = 9.02, p <$   
 207  $.01, \eta p^2 = .36$ ). Bonferroni corrected paired samples t-tests show that the main effect was driven by  
 208 significant facilitation of RTs on valid trials compared to invalid trials (valid: 368 ms; invalid: 389 ms;  
 209  $t_{(16)} = 4.91, p < .016$ ) and valid trials compared to Centre trials (valid: 368 ms; Centre: 407 ms;  $t_{(16)} =$   
 210  $3.62, p < .016$ ). RTs on invalid trials were also faster than those on Centre trials, but this effect was  
 211 not significant. (valid: 389 ms; Centre: 407 ms;  $t_{(16)} = 1.65, p = .12$ ). In contrast, there was no effect of

212 validity in the Saccadic response condition (valid: 276; invalid 278; Centre 264ms;  $F_{(2,32)} = 2.36, p =$   
 213  $.11, \eta^2p^2 = .13$ ).



214 .  
 215 **Figure 2:** Response Type x Cue validity interaction. Error bars show within-subject 95% Confidence  
 216 Intervals (Cousineau 2005).

217  
 218 **\*\*FIGURE 2\*\***

219  
 220 *False Alarms*

221 We examined the frequency of erroneous eye-movements on trials in which a cue but no  
 222 target was presented (Target Absent trials). Overall the number of erroneous saccades was very low  
 223 in the Manual Response condition (<1% of trials), so the data are not further described. In contrast,  
 224 in the Saccade Response condition participants failed to withhold any saccadic eye-movement on

225 16% of trials. Table 1 shows the raw frequency of erroneous saccades directed to the left and right in  
 226 the different cue conditions summed across subjects. The table indicates that erroneous saccades  
 227 were more common following peripheral cues, and that they were more likely to be directed  
 228 towards the cued location than the uncued location ( $\chi^2_{(2, n=17)} = 69, P < 0.05$ ). However, it should be  
 229 noted that these frequencies are summed across all participants so some of the values may not be  
 230 truly independent. As a consequence, the results of this test should be interpreted with caution.

Table 1: Direction of saccadic errors in the 'No Target' condition (% of total errors)

	Peripheral Left Cue	Peripheral Right Cue	Centre Cue
Left Saccade	71%	15%	14%
Right Saccade	10.7%	76%	13.3%

231

232

### 233 *Accuracy*

234 Participants performed the tasks with a high degree of accuracy (97% and 93.7% correct responses  
 235 on target-present trials in the Manual and Saccadic response conditions respectively), so we do not  
 236 report further analysis of these data.

237

### 238 **Discussion**

239 This study tested the hypothesis that transient offset cues would summon attention without  
 240 triggering activation of a saccade plan. Consistent with this hypothesis valid cues produced  
 241 significant RT facilitation for manual responses but not saccadic response. On first inspection these  
 242 data appear to show that attention was oriented to the cued location but that no saccade plan was  
 243 activated. However, there are several reasons to be cautious about accepting this interpretation.  
 244 Firstly, we also observed an increased false alarm rate when cues appeared in the periphery in the  
 245 Saccadic response condition but not the Manual response condition. The fact that saccadic errors  
 246 were more likely in the peripheral cue condition, and that these errors were systematically biased

247 towards the cued location might be taken as evidence that there was some cue-related oculomotor  
248 activation. Secondly, the proportion of catch trials was relatively high (30%). This is potentially  
249 problematic as the high proportion of catch trials meant the likelihood of participants being required  
250 to make a saccade to a cued location is relatively low, and Belopolsky and Theeuwes (2009) have  
251 argued that oculomotor priming effects are reduced when a saccadic target is unlikely to appear at a  
252 cued location.

253         Experiment 1 failed to show any effect of transient offset on saccadic RT, which might be  
254 due to the numerous false-alarm response type and the proportion of catch trials. To address these  
255 issues we conducted a second experiment in which we used a saccadic localisation task to assess  
256 oculomotor programming and two different measures of covert attention- a manual detection task  
257 and a manual discrimination task. The detection task allowed us to directly compare the results of  
258 experiments 1 and 2. However, having a target on every trial introduced the possibility that  
259 participants would strategically prepare their response at the start of the trial, rather than wait until  
260 target presentation. This strategy could mask any cueing effects. A discrimination task controls for  
261 this probability, as the participant cannot pre-prepare a response. If the failure to observe  
262 oculomotor priming by offset cues was due to the presence of catch trials, removing catch trials  
263 should elicit oculomotor priming in the saccade task and attentional facilitation in the manual  
264 detection and discrimination tasks.

265

## 266 **Experiment 2**

267

### 268 ***Design:***

269 Within each block there were three trial types (1) valid trials where the target appeared at the cued  
270 location (2) invalid trials where the target appeared contralateral to the cue and (3) Centre cue trials  
271 the fixation point was cued and the target appeared at one of the two peripheral locations. The  
272 target appeared at the cued location on 1/3<sup>rd</sup> of trials. The peripheral cue was the disappearance

273 and the reappearance of one of the two peripheral placeholders. In the Manual Detection task  
 274 participants were instructed to maintain fixation and press a button on the response box as quickly  
 275 as possible when the target appeared. In the Manual Discrimination task the response box was  
 276 aligned so the buttons lay along the sagittal midline. Participants pressed the upper button for a  
 277 vertical bar and the lower button for a horizontal bar. In both these tasks fixation was monitored by  
 278 recording eye-movements. In the Saccadic Localisation task participants were instructed to look as  
 279 quickly as possible at the target. Each participant completed one block of 20 practice trials and 6  
 280 blocks of 60 experimental trials (2 Manual Detection, 2 Manual Discrimination and 2 Saccade  
 281 Localisation). Each block of trials contained 20 valid trials, 20 invalid trials, 20 central cue trials.

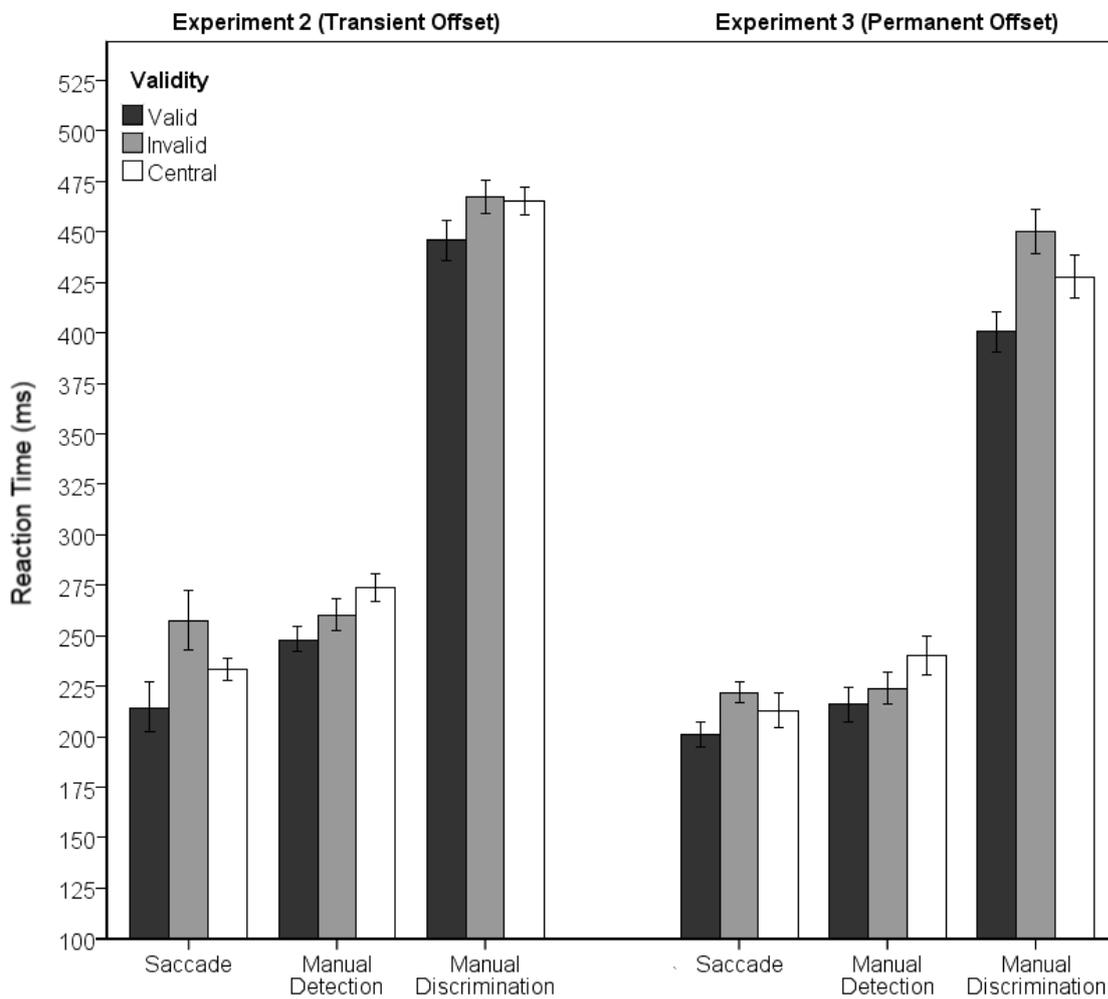
282

### 283 Results

284 Inspection of Figure 3 suggests that reaction times were faster in the valid cue condition than  
 285 the invalid cue condition in all of the tasks. Unlike Experiment 1, there is clear evidence of facilitation  
 286 of saccadic reaction times. However, while valid trials appear to facilitate RTs for all response types  
 287 there appear to be differences in the costs associated with invalid cues. To test this more formally,  
 288 the median (S)RT were subjected to a  $3 \times 3$  ANOVA with within-subjects factors of Response Type  
 289 (Saccade, Manual Detection, Manual Discrimination) and validity (valid, invalid and central cue).  
 290 Where the assumption of sphericity was violated we have reported Geisser-Greenhouse corrected  
 291 values. The ANOVA revealed a 2- way interaction between Response Type and validity ( $F_{(2,17.7)} =$   
 292  $3.69$ ,  $p < .05$ ,  $\eta^2 = .29$ ). One way ANOVA at each level of Response Type revealed a significant  
 293 validity effect in all 3 response types (Saccade:  $F_{(1.2,11.6)} = 12.03$ ,  $p < .05$ ; Manual Detection  $F_{(2,18)} =$   
 294  $11.1$ ,  $p < .05$ ; Manual Discrimination  $F_{(2,18)} = 4.07$ ,  $p < .05$ ). However, the pattern of costs/ benefits of  
 295 cueing differed across response types. Specifically, in the Saccadic Localisation task there were  
 296 significant RT benefit in the valid condition cues compared to the invalid condition ( $t_{(9)} = 3.67$ ,  $p <$   
 297  $.017$ ) and Central condition ( $t_{(9)} = 3.34$ ,  $p < .017$ ) and significant RT costs in the invalid condition  
 298 compared to the Central condition ( $t_{(9)} = 3.06$ ,  $p < .017$ ). In contrast, in the Manual detection task the

299 RT facilitation for the valid condition compared to the invalid condition was much less robust (248ms  
 300 vs 260ms,  $t_{(9)} = 2.16, p = .059$ ) and both were faster than the Central cue condition ( $t_{(9)} = 5.63, p <$   
 301  $.01; t_{(9)} = 2.33, p = .052$  respectively). In the Manual Discrimination task there was a significant RT  
 302 benefit in the valid condition compared to the invalid condition ( $t_{(9)} = 2.92, p = .017$ ) and the Central  
 303 condition ( $t_{(9)} = 2.97, p = .016$ ), but no cost for invalid condition compared to Centre condition ( $t_{(9)} =$   
 304  $.41, p = .69$ ). These data are illustrated in Figure 3.

305



306

307 **Figure 3:** Response Type x Cue validity interaction in Experiment 2 (left) and Experiment 3 (right).

308 Error bars show within-subject 95% Confidence Intervals (Cousineau 2005).

309

310 As with Experiment 1, participants performed the tasks with a high degree of accuracy (mean error  
311 rate was <4%) so we did not conduct further analysis of these data.

312

### 313 **Discussion**

314 This experiment tested the hypothesis that the failure to observe a cueing effect in the  
315 saccadic response condition of Experiment 1 was due to the presence of catch trials, rather than a  
316 failure of the cue to trigger saccade programming per se. Consistent with this explanation, removing  
317 the catch trials in Experiment 2 led to a reliable facilitation of saccadic reaction time in the valid  
318 condition and a reliable cost in the invalid condition. However, removing catch trials had a different  
319 effect on the Manual Detection task, such that the RT facilitation for the valid condition compared to  
320 the invalid condition was much reduced. On first inspection this might suggest that the peripheral  
321 cue was less effective at summoning attention. However, given that there were significant cueing  
322 effects in the Discrimination task, a more plausible explanation is that the attentional effects of a  
323 valid cue in the detection task were masked by the anticipatory effect of knowing that a target  
324 would appear on every trial. The fact that reaction times were ~100ms faster in Experiment 2 than  
325 Experiment 1 is consistent with this interpretation. Taken together with the false alarm data from  
326 Experiment 1, these results suggest that transient offsets elicit both oculomotor preparation and  
327 exogenous covert orienting, consistent with the idea that covert exogenous attentional facilitation is  
328 tightly coupled with activation of the eye-movement system (Smith & Schenk 2012).

329 One potentially important difference between the oculomotor and manual tasks is that the  
330 oculomotor task required localization, whereas the manual tasks do not. It seems likely that using a  
331 manual localisation task would have produced results more similar to that saccadic localisation task.  
332 However it is necessary to be cautious when interpreting the results of manual localisation tasks in  
333 terms of attentional processing because they confound the validity of a cue with stimulus-response  
334 compatibility effects. As a consequence, it is impossible to know whether changes in RT at the cued

335 location are due to enhanced attentional processing, a stimulus-response compatibility effect or  
 336 some combination of the two.

337 The results of this experiment suggest that transient offsets elicit both attentional and  
 338 oculomotor facilitation. However, a transient offset necessarily involves the re-appearance of the  
 339 cue after it has vanished. Given that object appearance is highly salient, one might argue that using a  
 340 transient offset does not provide a strong test of the idea that offsets elicit attentional capture but  
 341 not oculomotor priming. To address this issue we conducted a 3<sup>rd</sup> experiment in which attention was  
 342 summoned by the permanent removal of the placeholder.

343

### 344 **Experiment 3**

345

#### 346 **Method**

347 *Procedure:* As in experiment 2, except that the cue was the permanent offset of one of the  
 348 peripheral placeholders

349

#### 350 **Results & Discussion**

351 The median (S)RT was calculated for all correct responses for each individual. The RTs were  
 352 then subjected to a 3 × 3 ANOVA with within-subjects factors of Response Type (Oculomotor,  
 353 Manual Detection, Manual Discrimination) and validity (valid, invalid and central cue). Where the  
 354 assumption of sphericity was violated we have reported the Geisser-Greenhouse corrected values.  
 355 The ANOVA revealed a 2- way interaction between Response Type and validity ( $F_{(4,36)} = 5.7$ ,  $p < .05$ ,  
 356  $\eta^2 = .39$ ). One way ANOVA at each level of response type revealed a significant validity effect in all 3  
 357 response types (Saccade:  $F_{(2,18)} = 8.02$ ,  $p < .05$ ,  $\eta^2 = .47$ ; Manual Detection  $F_{(2,18)} = 6.8$ ,  $p < .05$ ,  $\eta^2 =$   
 358  $.43$ ; Manual Discrimination  $F_{(2,18)} = 18.82$ ,  $p < .05$ ,  $\eta^2 = .68$ ). However, the pattern of costs/ benefits  
 359 of cueing differed in the 3 response types. Specifically, the Saccadic Localisation condition showed  
 360 significant RT benefits for the valid condition compared to the invalid condition ( $t_{(9)} = 6.08$ ,  $p < .016$ ),

361 but not the Central condition ( $t_{(9)} = 1.86, p = .096$ ) and the difference between the invalid Condition  
 362 and Central condition was not significant ( $t_{(9)} = 1.66, p = .13$ ). In contrast, the Manual detection task  
 363 showed no significant RT facilitation for valid trials compared to invalid trials ( $t_{(9)} = 1.35, p = .21$ ),  
 364 although the valid condition was significantly faster than the Central condition; ( $t_{(9)} = 3.3, p < .016$ ).  
 365 The difference between invalid Condition and Central condition was not significant after applying a  
 366 Bonferroni correction ( $t_{(9)} = 2.41, p = 0.04$ ). Unlike the detection task, in the Manual Discrimination  
 367 task there was a significant RT benefit for that valid condition compared to the invalid condition ( $t_{(9)}$   
 368  $= 6.23, p < .016$ ) and the Central condition ( $t_{(9)} = 3.49, p < .016$ ). The difference between invalid  
 369 Condition and Central condition was not significant after applying the Bonferroni correction ( $t_{(9)} =$   
 370  $2.64, p = .027$ ). These interactions are illustrated on Figure 3, right panel. To summarize, valid cues  
 371 produced robust facilitation in the Saccadic Localisation and Manual Discrimination tasks, and much  
 372 weak facilitatory effects in the Manual Detection task.

373 We also conducted an exploratory analysis that directly compared the results of experiments  
 374 2 and 3. Mixed model RM ANOVA with within participants factors of Response Type (Saccade,  
 375 Manual Detection, Manual Discrimination) and validity (valid, Central, invalid), and a between  
 376 subjects factor of Cue Type (Transient, Permanent) produced a Response type x validity interaction (  
 377  $F_{(4,72)} = , p < .05, \eta p^2 = .15$ ) and a 3 way interaction ( $F = 3.14, p < .05, \eta p^2 = .15$ ). The 3 way  
 378 interaction was analysed with 3 (validity) x 2 (Cue Type) ANOVAs at each level of response type. For  
 379 Saccadic and Manual Detection Responses there was a main effect of validity ( $F_{(2,36)} = 19.5, p < .05,$   
 380  $\eta p^2 = .52; F_{(2,36)} = 16, p < .05, \eta p^2 = .49$  respectively ) but no effect of Cue Type and no interaction.  
 381 However, In the Manual Discrimination task there was a main effect of validity ( $F_{(2,36)} = 24.5, p < .05,$   
 382  $\eta p^2 = .58$ ) and a significant validity x Cue Type interaction  $F_{(2,36)} = 4.03, p < .05, \eta p^2 = .18$ ). This  
 383 interaction appears to be caused by a significant increase in both the benefits of a valid cue and the  
 384 costs of an invalid cue in Experiment 3, compared to Experiment 2 (see figure 3).

385

## 386 General Discussion

387           In three different experiments we have shown that peripheral offsets reliably elicit both  
388 exogenous covert attention and oculomotor priming. However, the effects were very sensitive to the  
389 task context. Specifically, when participants made a saccadic response the presence of catch trials  
390 prolonged saccadic reaction times and eliminated the saccadic reaction time advantage in the valid  
391 condition (Exp.1). Removing the catch trials revealed a significant validity effect in the Saccadic  
392 localisation task but greatly reduced the magnitude of the cueing effect in the Manual detection  
393 task, probably because participants could begin planning their response as soon as the trial began  
394 (Exp 2 &3). Consistent with this account we observed large and robust validity effects for the harder,  
395 discrimination task in which the participants could not preprogram their response.

396           The finding that the presence of catch trials can make it hard to observe facilitation of  
397 saccadic reaction times by non-predictive, peripheral cues has important implications for the  
398 interpretation of a series of studies that use a dual-task method to argue against a coupling between  
399 attention and eye-movements (e.g. (e.g. Hunt & Kingstone, 2003; Klein, 1980; Klein & Pontefract,  
400 1994; MacLean et al., 2015). In these tasks participants must perform a discrimination task following  
401 a predictive peripheral cue. However, on 10-20% of trials the discrimination target is replaced with a  
402 saccade target that participants must fixate as quickly as possible. Klein and colleagues have  
403 repeatedly shown that the latency of the saccades towards the attended and unattended location  
404 are the same. They argue that the absence of faster saccadic RTs to the attended location means  
405 that attention can be deployed without a concurrent saccade plan and conclude that Premotor  
406 Theory (they actually use the term Oculomotor Readiness Hypothesis) is false. However, these  
407 experiments contain up to 90% of 'no-go' trials, much higher than the 33% we used in Experiment 1.  
408 Given our finding that high proportions of catch trials masks oculomotor priming effects in reaction  
409 time data, it may be more appropriate to interpret the null results of Klein and colleagues as  
410 'absence of evidence' of oculomotor priming rather than 'evidence of absence' of oculomotor  
411 priming.

412           An alternative explanation is that the coupling between covert attention and oculomotor  
413 programming depends on the probability that a saccade will be directed to the cued location. In an  
414 elegant study, Belopolsky and Theeuwes (2009) observed that when the probability of making a  
415 saccade to an attended location was low, covert attentional orienting was preserved but oculomotor  
416 priming abolished. They proposed that, consistent with premotor theory, an endogenous shift of  
417 attention required activation of a saccade plan. However, they argued that this plan could be rapidly  
418 suppressed in cases where the saccade target was likely to be spatially separate from the attended  
419 location. In this view, the apparent decoupling between oculomotor programming and exogenous  
420 attention observed in our Experiment 1 occurred because the saccade target appeared at the cued  
421 location on only 22% of trials, so participants could rapidly suppress cue-induced saccade  
422 programming in order to be ready to make a saccade to the correct location. The saccadic errors on  
423 'Catch' trials may have occurred when the suppression of the saccade program was slow or  
424 incomplete. Notably, as with Belopolsky and Theeuwes (2009), the coupling between oculomotor  
425 programming and covert attention was restored when the probability of a saccade being directed to  
426 the location of a peripheral cue was increased to 50% in Experiment 2. Our data therefore  
427 complement the findings of (Belopolsky & Theeuwes, 2009, 2012) by suggesting that dissociation  
428 between oculomotor programming and maintenance of endogenous covert attention also pertains  
429 to exogenous covert attention.

430           Why is it that offsets can produce oculomotor priming in the peripheral cueing task, but not  
431 in the remote distractor task (Hermens & Walker, 2010)? One possibility is that oculomotor priming  
432 partly depends on the task context. More specifically, Cole and Kuhn (2010) argued that offsets only  
433 capture attention when they are the sole visual transient in the display, or the participant has  
434 engaged an attentional set for offsets. Given that offset cues are known to generate relatively small  
435 antisaccade costs (Pratt & Trottier, 2005) which suggests they elicit weak activation of the eye-  
436 movement system, it may be that the presence or absence of other visual transients in the display is  
437 of critical importance for observing oculomotor capture by offsets. In our cueing tasks the offset was

438 the only visual transient, so even relatively weak activation of the oculomotor system may be  
439 sufficient to permit oculomotor capture by the offset. In contrast, in the RDE experiments using  
440 offsets, the offset of the distractor is typically accompanied by the onset of a target item. In this case  
441 the target onset signal would be much stronger than the distractor-offset signal, leading to a greatly  
442 attenuated RDE. A second possibility is that an offset event is not temporally processed by the  
443 oculomotor system the same way as an onset event. During an offset, as the system needs to  
444 disengage from the spatial location previously activated. One can speculate that this process might  
445 affect the timing of target selection. Indeed, Bompas and Sumner (2009) have shown that varying  
446 the contrast of a remote distractor systematically alters the SOA at which the RDE effect is maximal  
447 and (Born & Kerzel, 2011) observed that saccade latency is shortened when a target has a higher  
448 contrast than a distractor. Given that the optimal SOA for observing the RDE is modulated by the  
449 relative contrast of target and distractors and that previous studies of offsets typically use a single,  
450 0ms gap between target and distractor, it is possible that an RDE to offset distractors might be  
451 observed if multiple target-distractor gaps were tested.

452 To summarize, this study examined whether offset cues could trigger exogenous orienting  
453 without engaging saccade programming. The results of experiments 2 & 3 clearly show that offsets  
454 elicit both attentional and oculomotor priming, consistent with the idea that exogenous orienting of  
455 attention is tightly coupled to eye-movements. It is argued that studies using the Remote Distractor  
456 paradigm do not observed effects of offsets on saccadic reaction time because they contain  
457 multiple, simultaneous visual transients and the weak activation triggered by the offset of a  
458 distractor cannot competed with the strong activation triggered by an onset. In contrast, the Posner  
459 cueing task has sequential visual transients. In the absence of competition from other visual  
460 transients even the relatively weak oculomotor activation associated with offsets is sufficient to  
461 elicit oculomotor priming and attentional facilitation. We conclude that covert, exogenous orienting  
462 is tightly coupled to oculomotor activation, and that previous evidence of dissociations between the  
463 two, e.g. (Maclean et al., 2016) can be explained by the inclusion of a high proportion of catch trials.

464

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558 **Figure Captions**

559

560 Figure 1: Schematic of a trial from the valid condition illustrating the timing and stimuli used in  
561 experiments 1, 2 & 3.

562

563 **Figure 2:** Response Type x Cue validity interaction. Error bars show within-subject 95% Confidence  
564 Intervals (Cousineau 2005).

565

566 **Figure 3:** Response Type x Cue validity interaction in Experiment 2 (left) and Experiment 3 (right).  
567 Error bars show within-subject 95% Confidence Intervals (Cousineau 2005).