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4 **Inhibitory cueing effects following manual and saccadic responses**
5 **to arrow cues**6 **Yun Ding^{1,2} · Tao He^{1,2} · Jason Satel³ · Zhiguo Wang^{1,2,4,5}**
7

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10 **Abstract** With two cueing tasks, in the present study we ex-
11 amined output-based inhibitory cueing effects (ICEs) with
12 manual responses to arrow targets following manual or sac-
13 cadic responses to arrow cues. In all experiments, ICEs were
14 observed when manual localization responses were required
15 to both the cues and targets, but only when the cue–target
16 onset asynchrony (CTOA) was 2,000 ms or longer. In con-
17 trast, when saccadic responses were made in response to the
18 cues, ICEs were only observed with CTOAs of 2,000 ms or
19 less—and only when an auditory cue-back signal was used.
20 The present study also showed that the magnitude of ICEs
21 following saccadic responses to arrow cues decreased with
22 time, much like traditional inhibition-of-return effects. The
23 magnitude of ICEs following manual responses to arrow cues,
24 however, appeared later in time and had no sign of decreasing
25 even 3 s after cue onset. These findings suggest that ICEs
26 linked to skeletomotor activation do exist and that the ICEs
27 evoked by oculomotor activation can carry over to the
28 skeletomotor system.

Keywords Spatial attention · Inhibition of return · Eye 29
movements · Cueing paradigm · Inhibitory cueing effects 30

A peripheral onset cue can briefly capture attention and facil- 31
itate responses to targets at the same location (Jonides, 1981). 32
Later on, however, an inhibitory cueing effect (ICE) emerges 33
at the cued location and delays target responses (Berlucchi, Di 34
Stefano, Marzi, Morelli, & Tassinari, 1981; Cohen, 1981; 35
Posner & Cohen, 1984). This later ICE was named “inhibition 36
of return” (IOR) by Posner, Rafal, Choate, and Vaughan 37
(1985), to reflect the theoretical proposition that, once atten- 38
tion has left a location, it is inhibited to return. As a theoretical 39
construct implied in Posner et al. (1985), IOR entails both a 40
cause and an effect: “In cause, IOR occurs in the aftermath of 41
oculomotor activation” and “in effect, IOR is a long-lasting 42
response bias that affects overt and covert orienting” (Hilchey, 43
Klein, & Satel, 2014, p. 1604). For clarity, in the present 44
article we will use the term *ICE* rather than *IOR* to describe 45
cueing effects that may have been caused by IOR or, alterna- 46
tively, by other mechanisms functionally similar to it. 47

Posner and Cohen (1984) originally suggested that the ICE 48
evoked by peripheral cues was the result of sensory stimula- 49
tion (i.e., an input-based effect). Posner et al. (1985), however, 50
found that this ICE had no effect on the perceptual arrival time 51
of targets (see also Klein, Schmidt, & Müller, 1998; Maylor, 52
1985) but, nevertheless, biased eye movements away (see also 53
Clohessy, Posner, Rothbart, & Vecera, 1991). These findings 54
suggest that the observed ICE may actually represent a motor 55
bias against previously attended locations (i.e., an output- 56
based effect). Subsequent studies demonstrated that many 57
ICEs are closely linked with the oculomotor system (SC; 58
e.g., Dorris, Klein, Everling, & Munoz, 2002; Posner et al., 59
1985; Rafal, Calabresi, Brennan, & Sciolto, 1989; Sumner, 60
Nachev, Vora, Husain, & Kennard, 2004) and can be readily 61

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62 evoked in cueing tasks that require eye movement responses
63 (e.g., Chica, Taylor, Lupiáñez, & Klein, 2010; Klein &
64 Hilchey, 2011).

65 Although efficient orienting of the eyes is crucial for visual
66 selection, the skeletomotor system is what enables an individ-
67 ual to actually interact with objects in the external world.
68 Briand, Larrison, and Sereno (2000) found that ICes appeared
69 later for manual than for saccadic responses (but see Khatoon,
70 Briand, & Sereno, 2002). With S-cone stimuli that were invis-
71 ible to the superior colliculus (at least along the retinotectal
72 pathway), Sumner and colleagues (Sumner, 2006; Sumner
73 et al., 2004) observed ICes with manual but not with saccadic
74 responses. Zhang and Zhang (2011) also found that loading up
75 visual working memory interfered with ICes measured with
76 manual but not with saccadic responses. In addition, it has
77 been shown that ICes interact with the Simon effect
78 (Ivanoff, Klein, & Lupiáñez, 2002) and that ICes double in
79 magnitude when a nonresponding hand is placed on the key-
80 board (Ivanoff & Klein, 2001). All of these findings suggest
81 that the skeletomotor system may also play an important role
82 in the generation and expression of ICes. However, the use of
83 peripheral onset cues makes it difficult to determine whether
84 these ICes were also contributed to by a sensory deficit at the
85 cued location (e.g., Fecteau & Munoz, 2005; Müller &
86 Kleinschmidt, 2007; Satel, Wang, Trappenberg, & Klein,
87 2011). With central arrow cues and targets, Cowper-Smith,
88 Eskes, and Westwood (2013) observed slower reaching res-
89 sponses toward previously touched locations, providing clear
90 evidence that skeletomotor activation also gives rise to output-
91 based ICes. Although such an ICE does not meet the theoret-
92 ical definition of IOR (Hilchey et al., 2014; Posner et al.,
93 1985), it dovetails with the observation of inhibitory tags in
94 manual foraging (Thomas et al., 2006) and affords the func-
95 tion of biasing orienting toward novelty.

96 Manual reaching responses were required in Cowper-
97 Smith et al.'s (2013) study. With manual buttonpresses, how-
98 ever, Taylor and Klein (2000) observed no ICE in a similar
99 experimental setup. Since Fischer, Pratt, and Neggers (2003)
100 also failed to observe an ICE when participants made reaching
101 responses to central arrow targets, it seems unlikely that re-
102 sponse modes were behind these conflicting findings. One
103 other prominent methodological difference between these
104 two studies was that the cue–target onset asynchrony
105 (CTOA) was only 1,000 ms in Taylor and Klein's study,
106 whereas that in Cowper-Smith et al.'s was 2,800 ms. With
107 central arrow targets, discrimination of the arrow direction is
108 needed before a response can be issued. It is known that ICes
109 measured with discrimination responses take longer to emerge
110 on a behavioral level (e.g., Lupiáñez, Milán, Tornay, Madrid,
111 & Tudela, 1997). The primary purpose of the present study
112 was to clarify whether Taylor and Klein's (2000) failure to
113 observe ICes with manual button responses was due to their
114 relatively short CTOA. It is critical to clear up this issue,

115 because if ICes can be evoked by skeletomotor activation,
116 they should be observed when the skeletomotor system is
117 actively engaged by either manual reaches (as in Cowper-
118 Smith et al., 2013) or buttonpresses (as in Taylor & Klein,
119 2000).

120 As has been alluded to before, ICes linked to oculomotor
121 activation have been frequently reported in the literature (e.g.,
122 Abrams & Dobkin, 1994; Posner et al., 1985; Satel, Hilchey,
123 Wang, Story, & Klein, 2013; Satel & Wang, 2012; Taylor &
124 Klein, 2000; Wang, Satel, & Klein, 2012). Nevertheless, it
125 remains unclear whether these oculomotor ICes carry over
126 to the skeletomotor system. With saccadic responses to the
127 cue and manual responses to the target, Taylor and Klein
128 (2000) observed ICes of the same magnitude, regardless of
129 whether the cue and target were central arrows or peripheral
130 onsets. Fischer et al. (2003), however, observed ICes with
131 saccadic responses, but not with any type of manual response
132 to central arrow targets, and they concluded that “motor-based
133 IOR is restricted to the oculomotor system” (p. 379). This is
134 quite surprising, given that neural activation in the oculomotor
135 system certainly does carry over to the skeletomotor system
136 (e.g., Werner, 1993). A secondary purpose of the present study
137 was to reexamine this issue. Saccadic responses to central
138 arrow cues have been shown to evoke an oculomotor ICE—
139 that is, an ICE that satisfies the theoretical definition of IOR
140 (Hilchey et al., 2014). If oculomotor ICes do carry over to the
141 skeletomotor system, a robust ICE would also be revealed
142 with manual button responses to central arrow targets.

143 To achieve these goals, for the present study we adopted
144 two cueing tasks. Manual button responses were required to
145 central arrow targets in both tasks, whereas saccadic responses
146 were required to central arrow cues in one task (saccadic–
147 manual), and manual localization responses were required in
148 the other (manual–manual). On the basis of previous results,
149 we expected saccadic responses to the cues to evoke an
150 output-based ICE in the oculomotor system (e.g., Chica
151 et al., 2010; Satel & Wang, 2012; Taylor & Klein, 2000;
152 Wang et al., 2012). Manual button responses to the cues might
153 also evoke an ICE, but the results of Taylor and Klein (2000)
154 suggest otherwise. In four experiments, ICes were consistent-
155 ly observed with manual button responses to the cue—but
156 only when the CTOA was relatively long (2,000 ms or longer).
157 In addition, in these experiments we also examined the time
158 courses of ICes evoked by skeletomotor and oculomotor ac-
159 tivation (Exp. 4) and the boundary conditions under which
160 oculomotor ICes carry over to the skeletomotor system
161 (Exps. 1–3).

162 Experiment 1: visual cue-back signal

163 To examine ICes evoked by manual and saccadic responses to
164 arrow cues, we first replicated two of Taylor and Klein's

165 (2000) 24 cueing tasks, with the addition of a much longer
 166 CTOA. Nonpredictive central arrows were used as the cues,
 167 and manual localization responses were required to central
 168 arrow targets in both tasks. These two tasks were blocked—
 169 saccadic responses were made to the cues in the first task
 170 (saccadic–manual), whereas manual responses were made to
 171 the cues in the second task (manual–manual).

172 **Method**

173 **Participants** In all experiments reported here, all participants
 174 reported normal or corrected-to-normal visual acuity and had
 175 no visual, motor, or neurological abnormalities. They were
 176 paid 40 Yuan per hour for their participation. Twenty-three
 177 volunteers participated in Experiment 1. One of these was
 178 excluded from the analysis because she did not finish the
 179 tasks. The mean age of the remaining 22 participants (17 fe-
 180 males, five males) was 20.82 years.

181 **Apparatus and stimuli** The stimuli were presented on a
 182 17-in. CRT monitor, and the viewing distance was main-
 183 tained at about 62 cm with a chinrest. Stimulus presenta-
 184 tion and response registration were controlled with scripts
 185 written in Python. Eye movements were monitored with
 186 an EyeLink 1000 (SR Research) eyetracking system. The
 187 spatial resolution of the eyetracker was 0.2° or better, and
 188 the sampling rate was set to 500 Hz.

189 The stimuli were similar to those of Taylor and Klein
 190 (2000). Three gray placeholder boxes subtended 1.8° (visual
 191 angle) were visible at all times. The center-to-center distance
 192 between two adjacent boxes was 9°. Both the cue and target
 193 stimuli were arrows presented in the central box, measuring
 194 0.8° (width) by 0.2° (height).

195 **Design and procedure** The sequence of events in both
 196 tasks is illustrated in Fig. 1. Self-paced drift correction
 197 was performed at the beginning of each trial, with suc-
 198 cessful drift correction signaled by a beep. Then a fixa-
 199 tion cross appeared in the central box, and an error
 200 message was displayed if eye movements were detected
 201 during a 500-ms fixation period. The cue was an arrow
 202 presented for 300 ms in the central box, pointing either

left or right. In the manual–manual task, participants 203
 maintained fixation throughout a trial and pressed the 204
 “Z” and “/” keys in response to left- and right- 205
 pointing arrow cues, respectively. Failure to respond 206
 within 500 ms, pressing the wrong key, or making an 207
 eye movement triggered an error message and the ter- 208
 mination of the trial. In the saccadic–manual task, par- 209
 ticipants made saccades to the peripheral box indicated 210
 by the central arrow. If participants failed to initiate an 211
 eye movement within 500 ms, or if the eyes missed the 212
 center of the appropriate peripheral box by more than 213
 2.5°, an error message was displayed and the trial was 214
 terminated. Five hundred milliseconds after cue onset, 215
 the central box was brightened for 300 ms (visual cue- 216
 back signal). Participants maintained fixation in the 217
 manual–manual task, whereas they made saccades back 218
 to the central box in the saccadic–manual task. Failure 219
 to maintain fixation in the manual–manual task, or fail- 220
 ure to saccade back to the central box within 500 ms, 221
 would trigger an error message and the termination of 222
 the trial. Unlike Taylor and Klein (2000), who only 223
 tested a CTOA of 1,000 ms, in the present experiment 224
 we also tested a much longer CTOA (2,000 ms). These 225
 two CTOAs were intermixed within blocks of trials. So, 226
 1,000 or 2,000 ms following cue onset, an arrow target 227
 appeared in the central box and participants quickly 228
 responded with the “Z” or the “/” key. An error mes- 229
 sage was displayed if saccades were detected before the 230
 target response or if the participant pressed the wrong 231
 key. 232

In the present experiment, we adopted a 2 (Task: 233
 manual–manual vs. saccadic–manual) × 2 (CTOA: 1, 234
 000 vs. 2,000 ms) × 2 (Cueing: cued vs. uncued) 235
 within-subjects design. Each experimental cell was test- 236
 ed for 32 trials, and thus each participant needed to 237
 successfully complete a total of 256 trials. The manu- 238
 al–manual and saccadic–manual tasks were blocked and 239
 counterbalanced across participants. Whenever an error 240
 message was displayed, the trial was discarded and later 241
 presented to the participants in a random order, until all 242
 trials had been completed successfully. The participants 243
 could take a break after every 80 trials, and a practice 244

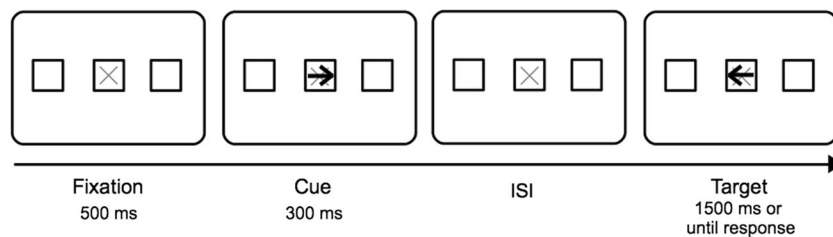


Fig. 1 The display sequence in a sample trial. Participants always made manual localization responses to the target, but also made manual (in the manual–manual task) or saccadic (in the saccadic–manual task) responses to the cue. For illustration purposes, the stimuli are not drawn to scale

245 block of eight trials was provided at the beginning of
 246 each task.

247 **Results**

248 All statistical analyses were performed in R (R Development
 249 Core Team, 2015). The effect size measure reported for anal-
 250 yses of variance (ANOVAs) was generalized eta squared (η_G^2 ;
 251 small size = .02, medium size = .13, and large size = .26; see
 252 Bakeman, 2005).

253 **Target RTs** Only successfully completed trials were consid-
 254 ered in the response time (RT) analysis. These RTs were
 255 cleansed on a per-participant, per-experimental-cell basis,
 256 using the nonrecursive method recommended by Van Selst
 257 and Jolicœur (1994). After outlier removal, 97.78 % and
 258 97.22 % of the trials remained in the manual–manual and
 259 saccadic–manual tasks, respectively.

260 The mean target RTs in all conditions are presented in
 261 Table 1. A repeated measures ANOVA was performed, reveal-
 262 ing significant main effects for task [$F(1, 21) = 14.71, MSE =$
 263 $3,749, p < .001, \eta_G^2 = .11$] and CTOA [$F(1, 21) = 17.97, MSE$
 264 $= 954, p < .001, \eta_G^2 = .04$]. RTs were generally longer in the
 265 saccadic–manual task, and were longer in the short-CTOA
 266 conditions. The main effect of cueing did not reach signifi-
 267 cance [$F(1, 21) = 2.80, MSE = 1,014, p = .11, \eta_G^2 = .01$], but a
 268 two-way interaction between cueing and CTOA was observed
 269 [$F(1, 21) = 20.07, MSE = 96.6, p < .001, \eta_G^2 = .005$], sug-
 270 gesting that the magnitudes of ICEs differed across CTOAs.
 271 The two-way interaction between CTOA and task approached
 272 significance [$F(1, 21) = 3.39, MSE = 553.9, p = .08, \eta_G^2 =$
 273 $.001$], whereas that between cueing and task did not reach
 274 significance [$F(1, 21) = 1.55, MSE = 443.4, p = .23, \eta_G^2 =$
 275 $.002$]. The three-way interaction between task, cueing, and
 276 CTOA was not significant [$F(1, 21) = 2.13, MSE = 130.2, p$
 277 $= .16, \eta_G^2 = .001$].

278 Taylor and Klein's (2000) empirical findings and their
 279 theory predicted no ICE in the manual–manual task and a
 280 robust ICE in the saccadic–manual task. Thus, planned
 281 comparisons were performed to evaluate the ICEs in all
 282 conditions, even though the three-way interaction did not
 283 reach significance. A reliable ICE (21 ms) was observed
 284 in the manual–manual task when the CTOA was 2,000 ms
 285 [$t(21) = 4.06, p < .001$], but the ICEs in all other condi-
 286 tions did not reach significance [all $t_s < 1.08$, all $p_s > .29$]
 287 (see Fig. 2a).

288 **Target response errors** Trials with erroneous eye move-
 289 ments or responses were aborted and recycled. Most
 290 recycled trials were terminated before target presentation;
 291 only those recycled due to incorrect target responses were
 292 considered in the response error analysis. Target response
 293 errors are presented in Table 1. Analyses revealed a

Table 1 Mean target response times (RTs), error rates, and RT differences between cued and uncued conditions (ICEs) in the manual–manual and saccadic–manual tasks of Experiments 1–4

t1.1	CTOA (ms)	Target Response Time (ms)		Target Response Errors (%)		ICE		Saccadic–Manual		Manual–Manual		Saccadic–Manual		Manual–Manual	
		Cued	Uncued	Cued	Uncued	Cued	Uncued	Cued	Uncued	Cued	Uncued	Cued	Uncued	Cued	Uncued
		Manual–Manual		Saccadic–Manual		Manual–Manual		Saccadic–Manual		Manual–Manual		Saccadic–Manual		Manual–Manual	
Exp. 1	1,000	375 (29.83)	372 (38.31)	3	415 (61.13)	415 (73.57)	0	3.24 (3.33)	1.11 (1.77)	2.13*	3.82 (4.29)	2.57 (2.98)	1.25	3.82 (4.29)	2.57 (2.98)
t1.5															
t1.6	2,000	371 (25.95)	350 (32.28)	21***	393 (54.35)	385 (61.90)	8	4.09 (3.68)	1.76 (1.77)	2.33*	1.28 (2.11)	2.08 (3.40)	-0.8	1.28 (2.11)	2.08 (3.40)
t1.7	1,000	378 (48.11)	383 (39.17)	-5	463 (58.76)	457 (60.77)	6	1.71 (3.14)	2.06 (2.33)	-0.35	3.57 (4.15)	5.40 (3.92)	-1.83	3.57 (4.15)	5.40 (3.92)
t1.8	2,000	381 (35.59)	359 (30.07)	21***	412 (55.41)	406 (47.10)	6	2.47 (5.32)	3.48 (5.13)	-1.01*	2.05 (2.84)	3.17 (4.76)	-1.12	2.05 (2.84)	3.17 (4.76)
t1.9	1,200	377 (34.78)	378 (28.06)	-1	484 (49.74)	463 (65.61)	20*	3.51 (5.35)	2.68 (3.91)	0.82	2.55 (2.91)	2.57 (2.70)	-0.02	2.55 (2.91)	2.57 (2.70)
t1.10	2,000	381 (38.29)	360 (25.74)	21**	437 (65.40)	418 (44.84)	19*	6.17 (7.78)	1.69 (2.68)	4.47*	1.05 (1.42)	2.33 (5.20)	-1.28	1.05 (1.42)	2.33 (5.20)
t1.11	1,200	387 (35.11)	378 (33.69)	9	475 (64.20)	446 (57.36)	29***	2.70 (3.38)	2.98 (3.85)	-0.28	3.44 (5.76)	3.58 (5.14)	-0.14	3.44 (5.76)	3.58 (5.14)
t1.12	2,000	383 (31.62)	367 (41.36)	16*	414 (61.12)	392 (48.59)	22**	4.24 (4.91)	1.58 (2.40)	2.66	2.22 (3.80)	2.30 (4.38)	-0.07	2.22 (3.80)	2.30 (4.38)
t1.13	3,000	387 (48.68)	360 (36.78)	26**	396 (49.07)	386 (40.26)	10	4.67 (4.29)	3.03 (3.74)	1.64	1.78 (2.49)	1.75 (2.89)	0.03	1.78 (2.49)	1.75 (2.89)

For easy comparison to the ICEs, error rate differences between cued and uncued conditions are also presented. The numbers in parentheses are SDs. * $p < .05$, ** $p < .01$, *** $p < .001$

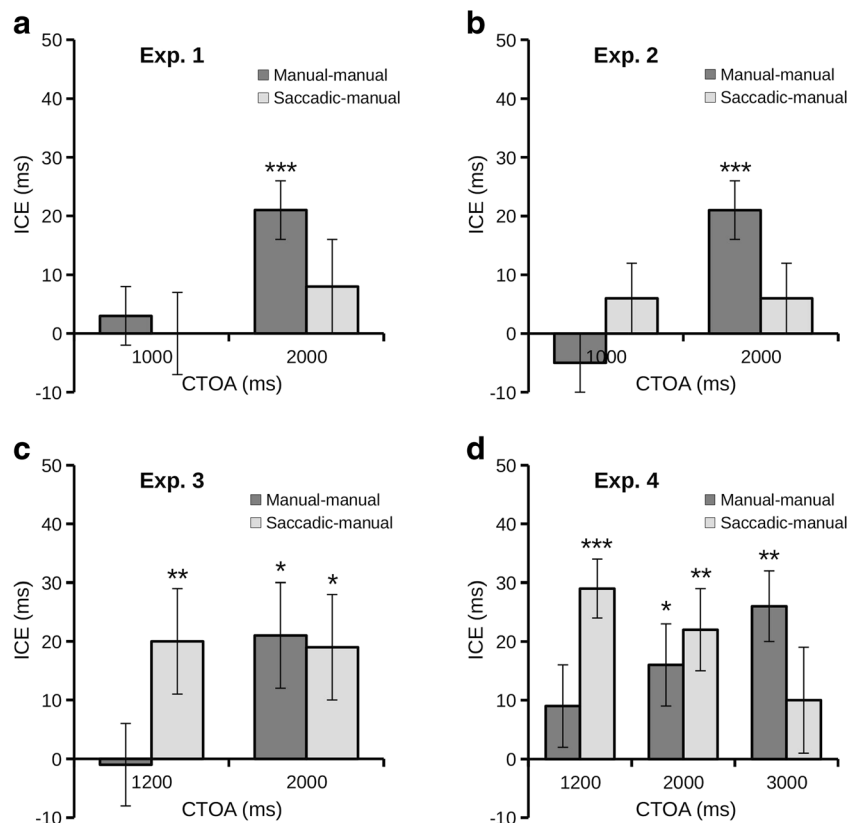


Fig. 2 Inhibitory cueing effects (ICEs) observed in all conditions of (a) Experiment 1 (visual cue back), (b) Experiment 2 (no cue back), (c) Experiment 3 (auditory cue back), and (d) Experiment 4 (time course). Error bars denote ± 1 SEM. * $p < .05$, ** $p < .01$, *** $p < .001$

294 marginal main effect for cueing [$F(1, 21) = 3.80$, $MSE =$
 295 17.47 , $p = .06$, $\eta_G^2 = .04$], with higher error rates ob-
 296 served in the cued conditions. A significant two-way in-
 297 teraction emerged between task and CTOA [$F(1, 21) =$
 298 15.86 , $MSE = 3.58$, $p < .001$, $\eta_G^2 = .04$], because the
 299 error rate decreased as the CTOA increased in the saccad-
 300 ic-manual task. The two-way interaction between cueing
 301 and task was marginally significant [$F(1, 21) = 4.09$, MSE
 302 $= 10.78$, $p = .06$, $\eta_G^2 = .03$]; the error rate was higher in
 303 the cued condition, but only in the manual-manual task.
 304 All other effects did not reach significance [all F s < 2.64 ,
 305 all p s $> .11$].

306 **Discussion**

307 In the manual-manual task, an ICE was observed for the
 308 long, but not the short, CTOA, suggesting that their rel-
 309 atively short CTOA (1,000 ms) might be the reason for
 310 Taylor and Klein's (2000) failure to observe an ICE in
 311 this task. Although Taylor and Klein (2000) observed
 312 reliable ICEs in their saccadic-manual tasks, no ICE
 313 was observed in the present experiment, regardless of
 314 the CTOA. Note that, in Taylor and Klein's study, central
 315 arrow cues and peripheral onset cues were intermixed
 316 within blocks of trials. It is possible that this unique

manipulation may have created an attentional set that
 gave rise to the ICEs observed in their saccadic-manual
 condition.

To closely replicate Taylor and Klein's (2000) design, we
 also used a visual cue-back signal to encourage the partici-
 pants to orient attention back to the central fixation. In the
 saccadic-manual task, this cue-back signal stimulated the ret-
 inal locus corresponding to the uncued box, and thus may
 have invoked inhibition there (Wang et al., 2012). Although
 it is unclear whether this retinal stimulation could delay re-
 sponses toward the uncued box, we eliminated this potential
 methodological confound in subsequent experiments.

Experiment 2: no cue-back signal

Experiment 2 was similar to Experiment 1, except that the
 visual cue-back signal was eliminated.

Method

Participants Twenty-two volunteers (14 females, eight males;
 mean age: 22.42 years) participated in Experiment 2.

335 **Apparatus, task procedure, and design** The apparatus,
 336 task procedure, and design were identical to those of
 337 Experiment 1, except that the visual cue-back signal
 338 was eliminated and, in the saccadic–manual task, the
 339 participants were instructed to quickly saccade back to
 340 the central box, immediately after the eyes had reached
 341 the peripheral box indicated by the cue. As in
 342 Experiment 1, any incorrect eye movements or responses
 343 resulted in trial termination and recycling.

344 **Results**

345 **Target RTs** The RTs from successfully completed trials
 346 were cleansed using the same protocol as in Experiment
 347 1. After data cleaning, 97.80 % and 96.86 % of the
 348 trials remained in the manual–manual and saccadic–
 349 manual tasks, respectively.

350 The mean target RTs are presented in Table 1. A re-
 351 peated measures ANOVA revealed significant main ef-
 352 fects for task [$F(1, 21) = 52.49, MSE = 2,964, p <$
 353 $.001, \eta_G^2 = .29]$ and CTOA [$F(1, 21) = 82.43, MSE =$
 354 $518, p < .001, \eta_G^2 = .1]$. RTs were generally longer in
 355 the saccadic–manual task, and were longer for the short-
 356 CTOA conditions. The main effect of cueing was marginally significant [$F(1, 21) = 3.15, MSE = 728.2, p = .09, \eta_G^2 = .01]$. Significant two-way interactions occurred between cueing and CTOA [$F(1, 21) = 8.71, MSE = 211.3, p < .01, \eta_G^2 = .005]$, due to a larger ICE in the longer-CTOA condition of the manual–manual task, and between task and CTOA [$F(1, 21) = 24.65, MSE = 748, p < .001, \eta_G^2 = .05]$, because the speeding up of RTs at the long CTOA was greater for the saccadic–manual task. The two-way interaction between cueing and task was not significant [$F(1, 21) = 0.24, MSE = 263.24, p = .63, \eta_G^2 = .00]$, whereas the three-way interaction was [$F(1, 21) = 8.16, MSE = 229.3, p < .01, \eta_G^2 = .004]$. Planned comparisons revealed an ICE (21 ms) for the manual–manual task when the CTOA was 2,000 ms [$t(21) = 4.16, p < .001]$. The ICEs in all other conditions did not reach significance [all t s < 0.96 , all p s $> .35]$ (see Fig. 2b).

374 **Target response errors** Response error rates are also pre-
 375 sented in Table 1. A repeated measures ANOVA re-
 376 vealed a significant main effect of cueing [$F(1, 21) =$
 377 $6.33, MSE = 8.10, p = .02, \eta_G^2 = .02]$, with more errors
 378 occurring in uncued conditions. A significant two-way
 379 interaction between task and CTOA was also observed
 380 [$F(1, 21) = 8.83, MSE = 3, p < .01, \eta_G^2 = .03]$, because
 381 the error rate decreased as the CTOA increased only in
 382 the saccadic–manual task. All other effects did not reach
 383 significance [all F s < 1.31 , all p s $> .26]$.

Discussion

The results of Experiment 2 were consistent with those of Experiment 1 (see Fig. 2a and b).¹ In the manual–manual task, an ICE was observed only at the long CTOA; in the saccadic–manual task, no ICE was observed at either CTOA. Our failure to observe an ICE in the saccadic–manual task was in drastic contrast to previous observations of ICEs in similar tasks (e.g., Posner et al., 1985; Taylor & Klein, 2000). However, since previous work has demonstrated the importance of the cue-back signal in revealing ICEs (e.g., Pratt & Fischer, 2002; Prime & Jolicœur, 2009; but see Possamaï, 1991), it is possible that we failed to observe ICEs in the saccadic–manual task because Experiment 2 did not include cue-back signals. This possibility was explored in Experiment 3 through the use of an auditory cue-back signal. With auditory cue-back signals, Satel and Wang (2012) observed robust ICE in a similar experimental setup.

Experiment 3: auditory cue-back signal

Experiment 3 followed the same design as Experiments 1 and 2, except that an auditory cue-back signal was used to reorient attention to the central fixation following responses to the cues.

Method

Participants A total of 16 participants (15 females, one male; mean age: 21.2 years) took part in Experiment 3.

Apparatus, task procedure, and design The apparatus, stimuli, and task procedure were the same as in Experiment 1, except that (a) the visual cue-back signal was replaced by an auditory beep, and (b) the short CTOA was extended to 1,200 ms, so as to allocate enough time for participants to respond to the cue-back signal.

Results

Target RTs After data cleansing, 97.70 % and 97.13 % of the successfully completed trials remained in the manual–manual and saccadic–manual tasks, respectively.

The mean target RTs in all conditions are presented in Table 1. An ANOVA of the RTs revealed significant main

¹ An ANOVA on the RTs, with Experiment (Exp. 1 vs. 2) as a factor, revealed a significant three-way interaction between cueing, CTOA, and task [$F(1, 42) = 9.98, p < .01, \eta_G^2 = .002]$. The four-way interaction involving experiment did not reach significance [$F(1, 42) = 1.97, p = .17, \eta_G^2 = .0004]$.

422 effects for task [$F(1, 15) = 75.68, MSE = 2,472, p < .001, \eta_G^2 = .42$], CTOA [$F(1, 15) = 21.82, MSE = 985, p < .001, \eta_G^2 = .08$], and cueing [$F(1, 15) = 5.16, MSE = 1,353, p < .05, \eta_G^2 = .03$]. The main effect of cueing emerged because RTs were generally longer for cued than for uncued targets, suggesting the observation of an overall ICE. The main effects of task and CTOA were due to faster responses in the manual–manual condition and at the long CTOA. A significant two-way interaction was observed between CTOA and task [$F(1, 15) = 24.47, MSE = 514, p < .001, \eta_G^2 = .05$], because there was a greater reduction in RTs at the longer CTOA in the saccadic–manual task. The two-way interactions between cueing and CTOA [$F(1, 15) = 3.25, MSE = 247.2, p = .09, \eta_G^2 = .003$] and cueing and task [$F(1, 15) = 3.31, MSE = 227.1, p = .09, \eta_G^2 = .003$] approached significance. The three-way interaction between task, cueing, and CTOA did not reach significance [$F(1, 15) = 2.87, MSE = 372.8, p = .11, \eta_G^2 = .004$]. Planned comparisons revealed that, consistent with Experiments 1 and 2, in the manual–manual task an ICE (21 ms) was observed only at the long CTOA (2,000 ms) [$t(15) = 2.39, p < .05$]. However, with auditory cue-back signals, ICEs emerged in the saccadic–manual task at both short (21 ms) [$t(15) = 2.23, p < .05$] and long (19 ms) [$t(15) = 2.20, p = .05$] CTOAs.

446 **Target response errors** Response error rates are also presented in Table 1. A repeated measures ANOVA revealed marginal main effects for task [$F(1, 15) = 4.40, MSE = 14.01, p = .05, \eta_G^2 = .03$], and cueing [$F(1, 15) = 4.34, MSE = 7.39, p = .05, \eta_G^2 = .01$]. Error rates were higher in the manual–manual task and in cued conditions. A marginal two-way interaction was observed between task and cueing [$F(1, 15) = 3.97, MSE = 21.93, p = .06, \eta_G^2 = .04$], because the effect of cueing was more prominent in the manual–manual task. The three-way interaction also reached marginal significance [$F(1, 15) = 3.84, MSE = 12.51, p = .07, \eta_G^2 = .02$], because the error rate increased with CTOA in the manual–manual task, whereas it decreased with CTOA in the saccadic–manual task. All other effects did not reach significance [all F s < 2.06, all p s > .17].

460 Discussion

461 Experiment 3 produced two important findings. First, with an auditory cue-back signal, reliable ICEs were observed in the saccadic–manual task. This was in contrast with the two previous experiments, in which no ICE was observed with a visual cue back (Exp. 1) or without any cue back (Exp. 2). It thus seems that, although making a saccadic response to a cue is sufficient to evoke an ICE (e.g., Posner et al., 1985; Rafal et al., 1989; Satel & Wang, 2012; Taylor & Klein, 2000), the ICE will only delay manual responses under certain conditions. Second, a reliable ICE was again observed only at the long CTOA in the manual–manual task.

Experiment 4: time course

472 The findings of Experiments 1–3 clearly show that (a) ICEs 473 can be evoked and revealed with arrow cues/targets and man- 474 ual localization responses, although only with sufficiently 475 long time intervals between the cue and target, and (b) ICEs 476 evoked by saccadic responses to arrow cues do carry over to 477 the skeletomotor system to delay manual responses. To further 478 understand these ICEs, it is necessary to characterize their 479 time courses. 480

Method

481 **Participants** Seventeen volunteers participated in Experiment 482 4. One of them was excluded from the analysis because she 483 did not finish the tasks. The mean age of the remaining 16 484 participants (13 females, three males) was 19.38 years. 485

486 **Apparatus, task procedure, and design** The apparatus, task 487 procedure, and design were the same as in Experiment 3, 488 except that three CTOAs (1,200, 2,000, and 3,000 ms), rather 489 than two, were tested.

Results

490 **Target RTs** After cleansing, 97.67 % and 97.17 % of the 491 successfully completed trials remained in the manual–manual 492 and saccadic–manual tasks, respectively. 493

494 The mean target RTs in all conditions are presented in 495 Table 1. A repeated measures ANOVA on the RTs revealed 496 significant main effects for task [$F(1, 15) = 52.44, MSE = 1, 497 554, p < .001, \eta_G^2 = .17$], CTOA [$F(2, 30) = 40.49, MSE = 498 687, p < .001, \eta_G^2 = .12$], and cueing [$F(1, 15) = 14.36, MSE = 499 1,187, p < .001, \eta_G^2 = .04$]. The RTs were generally longer in 500 the saccadic–manual task and for cued targets, and decreased 501 as the CTOA increased. A significant two-way interaction was 502 observed between task and CTOA [$F(2, 30) = 23.91, MSE = 503 710, p < .001, \eta_G^2 = .08$], due to a greater reduction in RTs as 504 CTOA increased in the saccadic–manual task. The two-way 505 interactions between cueing and CTOA [$F(1, 15) = 0.03, MSE 506 = 123.52, p = .97, \eta_G^2 = .00$] and cueing and task [$F(1, 15) = 507 0.49, MSE = 285, p = .49, \eta_G^2 = .00$] were not significant. The 508 three-way interaction between task, CTOA, and cueing was 509 significant [$F(2, 30) = 6.15, MSE = 218.5, p < .01, \eta_G^2 = 510 .006$], because the ICEs increased with CTOA in the manu- 511 al–manual task, whereas they decreased in the saccadic–man- 512 ual task (see Fig. 2d). Planned comparisons revealed that, in 513 the manual–manual task, ICEs were observed for the 3,000- 514 ms (26 ms) [$t(15) = 4.35, p < .01$] and 2,000-ms (16 ms) [$t(15) 515 = 2.54, p < .05$] CTOAs, but not for the 1,200-ms CTOA 516 [$t(15) = 1.28, p = .22$]. In the saccadic–manual task, ICEs were 517 observed for the 1,200-ms (29 ms) [$t(15) = 6.71, p < .001$] and

518 2,000-ms (22 ms) [$t(15) = 3.25, p < .01$] CTOAs, but not for
 519 the 3,000-ms CTOA [$t(15) = 1.16, p = .26$].

520 As is clear from Fig. 2d, the ICE generally decreased as the
 521 CTOA increased in the saccadic–manual task, much like the
 522 ICEs observed in the classic cueing paradigm (e.g., Fecteau &
 523 Munoz, 2005; Samuel & Kat, 2003). Confirming this trend, an
 524 ANOVA on the ICEs in the saccadic–manual task revealed a
 525 significant main effect of CTOA [$F(2, 30) = 4.15, MSE =$
 526 $354.4, p < .05, \eta_G^2 = .03$]. Pairwise comparisons revealed a
 527 significant difference in ICEs between the 1,200-ms and 3,
 528 000-ms CTOAs [$t(15) = 2.29, p < .05$], and a marginally
 529 significant difference between the 2,000-ms and 3,000-ms
 530 CTOAs [$t(15) = 2.09, p = .05$]; the difference between the 1,
 531 200-ms and 2,000-ms CTOAs did not reach significance
 532 [$t(15) = 1.25, p = .22$]. The manual–manual task, however,
 533 produced an ICE that started later and had no sign of decreas-
 534 ing at the longest CTOA tested in the present experiment (3,
 535 000 ms). An ANOVA of the ICEs in this task also revealed a
 536 significant effect of CTOA [$F(2, 30) = 3.72, MSE = 329.7, p <$
 537 $.05, \eta_G^2 = .04$]. Pairwise comparisons revealed only a signif-
 538 icant difference in ICE between the 1,200- and 3,000-ms
 539 CTOAs [$t(15) = 2.71, p < .05$]; the differences between the
 540 1,200- and 2,000-ms CTOAs [$t(15) = 1.28, p = .22$] and the 2,
 541 000- and 3,000-ms CTOAs [$t(15) = 1.44, p = .17$] did not
 542 reach significance.

543 **Target response errors** Response error rates are presented in
 544 Table 1. An ANOVA revealed only a significant two-way
 545 interaction between task and CTOA [$F(2, 30) = 3.49, MSE$
 546 $= 8.70, p < .05, \eta_G^2 = .02$]. Again, error rates appeared to
 547 increase with CTOA in the manual–manual task, but to de-
 548 crease with CTOA in the saccadic–manual task. All other
 549 effects did not reach significance [$F_s < 2.07, p_s > .14$].

550 **Discussion**

551 In Experiment 4, we examined the time courses of ICEs
 552 evoked by saccadic and manual responses. As is shown in
 553 Fig. 2d, the ICE in the saccadic–manual task generally de-
 554 creased as the CTOA increased, whereas that in the manual–
 555 manual task had a trend to increase with CTOA. It is unclear
 556 why this pattern of results emerged, but it is likely that the ICE
 557 in the manual–manual tasks originates from neurodynamic
 558 mechanisms that are distinct from the oculomotor IOR effects
 559 evoked by saccadic cue responses.

560 **General discussion**

561 With two cueing tasks, in the present study we examined
 562 output-based ICEs evoked by saccadic and manual localiza-
 563 tion responses to arrow cues. ICEs were consistently evoked
 564 and revealed with manual responses to arrow cues and targets

in all experiments—but only when the CTOA was 2,000 ms or 565
 longer. Following saccadic responses to arrow cues, ICEs 566
 were also observed, but only when an auditory cue-back sig- 567
 nal was supplied to reorient the participant’s gaze to the central 568
 fixation (Exps. 3–4). Furthermore, the present experiments 569
 show that the magnitudes of the ICEs evoked by saccadic 570
 responses generally decreased as the CTOA increased, mim- 571
 icking the pattern of ICEs observed with peripheral onset cues 572
 (Samuel & Kat, 2003). The ICEs evoked by manual responses 573
 to the cue, however, appeared later in time and did not de- 574
 crease even after 3 s had elapsed since cue onset (Exp. 4). 575

In the present experiments, the cues and targets were both 576
 arrows at fixation. One might suggest that the RT cost ob- 577
 served for targets pointing in the same direction as the cue 578
 might well be a shape-based, nonspatial repetition disadvan- 579
 tage (Fox & de Fockert, 2001; Riggio, Patteri, & Umiltà, 580
 2003). We believe that this is unlikely for several reasons. 581
 First, the visual and auditory cue-back signals could have 582
 functioned as the “neutral attractors” that are critical for non- 583
 spatial repetition disadvantages (Fox & de Fockert, 2001; 584
 Law, Pratt, & Abrams, 1995; Taylor & Klein, 1998). 585
 However, ICEs were not always observed when these neutral 586
 attractors were present (Exps. 1, 3, and 4). Second, the ICEs 587
 observed in the present experiments cannot be attributed sole- 588
 ly to a repetition disadvantage, because arrows can reflexively 589
 orient attention (e.g., Hommel, Pratt, Colzato, & Godijn, 590
 2001; Stevens, West, Al-Aidroos, Weger, & Pratt, 2008). 591
 Third, and most importantly, in Fox and de Fockert (2001) 592
 and other studies of nonspatial ICEs (e.g., Hu & Samuel, 593
 2011; Kwak & Egeth, 1992; Law et al., 1995; Taylor & 594
 Klein, 1998) the required detection or discrimination re- 595
 sponses entailed no spatial information, whereas in the present 596
 work, the arrow cues and targets both required spatial local- 597
 ization responses. Thus, the ICEs reported here cannot be 598
 regarded as nonspatial. 599

The most important finding of the present study was that a 600
 robust ICE was observed when simple manual localization 601
 responses were made to central arrow cues. This ICE may 602
 arise from habituation of overt orienting responses 603
 (Dukewich, 2009), or it may be “merely an epiphenomenon 604
 arising from neural adaptation within motor control networks” 605
 (Cowper-Smith et al., 2013). Regardless of the underlying 606
 mechanism(s), the available evidence seems to suggest that 607
 this ICE is linked to skeletomotor activation. This ICE does 608
 not depend on the type of manual response required—it can be 609
 evoked and revealed with either simple buttonpresses (present 610
 experiments) or reaching responses (Cowper-Smith et al., 611
 2013). Also, and more importantly, this ICE takes a longer 612
 time to emerge on a behavioral level than does “traditional 613
 IOR,” and its magnitude does not seem to decrease even after 614
 3 s have elapsed since cue onset. This unique time course is in 615
 dramatic contrast to those of other ICEs that have been report- 616
 ed in the literature (Klein, 2000, 2004; Samuel & Kat, 2003; 617

618 Wang et al., 2012). It is worth noting that the ICE evoked by
 619 oculomotor activation, as revealed by the saccadic–manual
 620 task, is largely dispersed 3 s after cue onset. These observa-
 621 tions dovetail with the finding that, in visual search tasks, IOR
 622 (or inhibitory) tags at manually searched locations (Thomas
 623 et al., 2006) last longer than those at previously fixated loca-
 624 tions (Dodd, Van der Stigchel, & Hollingworth, 2009), imply-
 625 ing that the oculomotor and skeletomotor systems are respon-
 626 sible for relatively fast and slow overt orienting, respectively.

627 Since the discovery of IOR, various ICEs have been shown
 628 to be closely tied to the oculomotor system (e.g., Dorris et al.,
 629 2002; Posner et al., 1985; Sapir, Soroker, Berger, & Henik,
 630 1999; Satel et al., 2011; Wang, Satel, Trappenberg, & Klein,
 631 2011). The term “oculomotor IOR” has been used in several
 632 recent studies to stress the importance of oculomotor activa-
 633 tion in the generation of ICEs (or IOR; e.g., Hilchey et al.,
 634 2014; Klein & Hilchey, 2011; Wang et al., 2012). In the pres-
 635 ent experiment, we explored whether oculomotor ICEs, when
 636 evoked by saccadic responses to central arrow cues, carry over
 637 to the skeletomotor system to delay manual responses. No ICE
 638 was observed when a visual (Exp. 1) or no (Exp. 2) cue-back
 639 signal was used in the saccadic–manual task. When an audi-
 640 tory cue-back signal was used in Experiments 3 and 4, how-
 641 ever, ICEs were observed in the saccadic–manual task at both
 642 short and long CTOAs. This pattern of results suggests that
 643 auditory cue-back signals are critical for oculomotor ICEs to
 644 transfer to the skeletomotor system.² However, given the
 645 methodological differences across experiments, this finding
 646 should not be overstated.

647 **Conclusions**

648 In the present study, we examined the output-based inhibitory
 649 cueing effects evoked by saccadic and manual localization
 650 responses to arrow cues. We showed that ICEs evoked by
 651 manual and saccadic responses to central arrow cues can both
 652 be revealed with manual target responses, and that the ICE
 653 evoked by manual cue responses has a unique time course. We
 654 conclude that ICEs linked to skeletomotor activation do exist
 655 and that oculomotor ICEs can carry over to the skeletomotor
 656 system to delay manual responses.

² This supposition was supported by an ANOVA of the RTs from the saccadic–manual tasks. Note that only the 1,200-ms and 2,000-ms CTOAs of Experiment 4 were considered, and that Experiments 1 and 2 were regarded as conditions without an auditory cue back. The results revealed a significant effect of cueing (cued vs. uncued) [$F(1, 62) = 21.65$, $MSE = 622$, $p < .001$, $\eta_G^2 = .02$] that interacted with the cue-back signal (with vs. without auditory cue back) [$F(1, 62) = 6.85$, $MSE = 622$, $p < .05$, $\eta_G^2 = .01$]. The three-way interaction involving CTOA (short vs. long) did not reach significance [$F(1, 62) = 0.63$, $MSE = 228.71$, $p = .43$, $\eta_G^2 = .00$]. The two-way interaction between cueing and cue-back signal suggests that the auditory cue back did play a role in the saccadic–manual task, which assessed whether oculomotor ICEs carry over to the skeletomotor system.

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