

Probing the time-course of facilitation and inhibition in gaze cueing of attention in an upper-limb reaching task

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Running Head: PROCESSING OF GAZE AND HAND CUES

1 **Abstract**

2 Previous work has revealed that social cues, such as gaze and pointed fingers, can lead to a shift
3 in the focus of another person's attention. Research investigating the mechanisms of these shifts
4 of attention has typically employed detection or localization button pressing tasks. Because in-
5 depth analyses of the spatio-temporal characteristics of aiming movements can provide
6 additional insights into the dynamics of the processing of stimuli, the current study used a
7 reaching paradigm to further explore the processing of social cues. In Experiments 1 and 2,
8 participants aimed to a left or right location after a non-predictive eye gaze cue towards one of
9 the target locations. Seven stimulus onset asynchronies (SOAs) between 100 and 2400 ms were
10 used. Both temporal (reaction time-RT) and spatial (initial movement angle-IMA) characteristics
11 of the movements were analysed. RTs were shorter for cued (gazed-at) targets than to uncued
12 targets across most SOAs. There were, however, no statistical differences in IMA between
13 movements to cued and uncued targets suggesting action planning was not affected by the gaze
14 cue. In Experiment 3, the social cue was a finger pointing to one of the two target locations.
15 Finger pointing cues generated significant cuing effects in both RT and IMA. Overall, these
16 results indicate that eye gaze and finger pointing social cues are processed differently.
17 Perception-action coupling (i.e., a tight link between the response and the social cue that is
18 presented) may play a role in the generation of action, and deviation of trajectories towards cued
19 and uncued targets.

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1 **Introduction**

2 During social interactions, individuals process the movements of other people for a
3 variety of purposes such as engaging in non-verbal communication, decoding intention, and
4 coordinating action. One important cue used during social interactions is the direction of eye
5 gaze. Indeed, gaze has been repeatedly shown to be a powerful biological orienting cue (e.g.,
6 Friesen & Kingstone, 1998; see Frischen, Bayliss, & Tipper, 2007 for review). Other cues, such
7 as a pointed finger, might act similarly (e.g., Ariga & Watanabe, 2009). Even though different
8 social cues are used for similar purposes, they are likely to be processed differently. Separate
9 regions of the extra-striate and other visual cortices process body and face stimuli (see Peelen &
10 Downing, 2007 for review), and there are separate networks of motor areas that process
11 information for the generation of hand and eye movements (Cisek & Kalaska, 2010; Kandel,
12 Schwartz, & Jessell, 2000). As such, pointing and gaze cues might also be decoded using
13 separate networks. The present paper reports a set of studies designed to further understanding of
14 the mechanisms involved in the processing of social gaze and pointing cues by using an upper
15 limb-reaching task. The spatial and temporal characteristics of reaching movements to target
16 locations were used here because such analyses can provide additional information concerning
17 the dynamics of the cognitive mechanisms involved in the cuing paradigm (see Song &
18 Nakayama, 2009; Welsh & Weeks, 2010).

19 **The Time-Course of Cuing Effects**

20 The present studies involved an adapted version of the conventional spatial cueing
21 paradigm (Posner, 1980; Posner & Cohen, 1984). In a common version of this paradigm, a
22 sudden onset cue is presented peripherally at one of two potential target locations. Even though
23 the cue is non-predictive of the target location, RTs are affected by the cue, with the direction of

1 this influence being dependent on the timing of the cue and target onsets (the stimulus onset
2 asynchrony; SOA). A facilitation effect of the cue (shorter RTs for targets at cued over uncued
3 locations) emerges at short (~ 100 ms) SOAs. This facilitation is thought to emerge because the
4 cue has rapidly drawn attention to its location. At SOAs longer than 300 ms, however, RTs are
5 actually longer to cued targets than to uncued targets (Posner & Cohen, 1984). This latter pattern
6 of longer RTs to cued than uncued targets is termed inhibition of return (IOR). It is thought that,
7 as a consequence of attention being redirected from the cued location back to the central fixation
8 point, a residual inhibitory code is placed on the location of the cue and/or on the response to the
9 cued location (Posner & Cohen, 1984; see Klein, 2000 for review). This inhibitory code hinders
10 the reorientation of attention back to the cued location and/or the processing of the sensory
11 information at the previously cued/attended location.

12 When the spatial cue is presented centrally, however, the time-course and pattern of
13 cuing effects is distinct from that which emerges when peripheral cues are used. While
14 peripheral cues typically illicit facilitation that peaks at very short SOAs (100ms), maximal
15 facilitation effects following central cues typically take longer to arise, occurring typically
16 around 300 ms. Further, IOR is typically not observed (Cheal & Lyon, 1991; Muller & Rabbitt,
17 1989). Consequently, peripheral and central cueing paradigms differ in the nature of their
18 behavioural effects on attention orienting and, because of these differences, they are often
19 thought to have separate loci of control. Therefore, it may be possible to distinguish the
20 mechanisms involved in processing the various cues based on the pattern of RTs to cued and
21 uncued targets that emerge following different types of cues (e.g., peripheral vs. central). Indeed,
22 the examination of the time-course of the cuing effects following the presentation of a central
23 face with gaze directed towards one of two placeholders has been central to longstanding debate

1 on whether or not gaze cues share the mechanisms involved in peripheral or central gaze cuing
2 (or an entirely different mechanism) (see Frischen, Bayliss, et al., 2007 for review).

3 **The Processing of Gaze and Finger-Point Cues**

4 The research on social gaze cues has revealed that these cues seem to share properties of
5 both peripheral and central cues. Because gaze cues are presented at central fixation and do not
6 involve a dynamic change in the periphery at a potential target location, gaze cues most resemble
7 central cues. However, the processing advantages (as seen in RTs) from gaze cues can resemble
8 peripheral cues in that they tend to show facilitation effects at very short SOAs (100-300 ms) and
9 these early facilitation effects are relatively immune to top-down influences such as the
10 instruction to ignore the gaze cue (e.g. Driver et al., 1999; Friesen & Kingstone, 1998, see
11 Frischen et al., 2007 for review). In contrast to the effects of peripheral cues (e.g., Posner &
12 Cohen, 1984), however, the facilitation effects stemming from gaze cues are still present at
13 longer SOAs (700-1000 ms) though the facilitation effects do gradually diminish (Frischen,
14 Bayliss, et al., 2007). Additionally, IOR is rarely observed in RTs following gaze cues, with the
15 exception of at SOAs greater than 2000 ms and only when there is an event to disengage
16 attention from the gazed-at location and draw it back to central fixation, such as a mask or an
17 offset of the gaze cue (Frischen, Smilek, Eastwood, & Tipper, 2007; Frischen & Tipper, 2004).
18 In sum, it is not clear from the data if the mechanisms involved in gaze cueing of attention are
19 most similar to those used in peripheral cueing, central cueing, or something different altogether.

20 The processing of finger pointing cues has received comparatively little study. In one of
21 the few studies to examine the time-course of cuing effects following pointing cues, Ariga and
22 Watanabe (2009) found that there was a facilitation effect at the pointed-to location at a short
23 (107ms) SOA, but no difference between RTs to targets at the pointed-to and non-pointed-to

1 location at a longer (1000ms) SOA. The pattern of cuing effects (short-term facilitation with no
2 IOR) is similar to that observed following gaze cues. Interestingly, IOR-like effects have been
3 observed when participants were required to reach and touch a target location more than 1200 ms
4 after a co-actor pointed to one of two targets (Experiment 3, Atkinson, Simpson, Skarratt, &
5 Cole, 2014). Specifically, RTs were longer for targets presented at locations that the co-actor had
6 previously pointed towards than for targets at the other location. These data suggest that the
7 mechanisms of IOR may be activated following a finger pointing stimulus. Overall, relatively
8 little research has been conducted on understanding the processing of finger cues, but these few
9 studies do suggest that these stimuli can generate shifts of attention.

10 **An Action-Centred Approach**

11 The extant work in this area of social cuing has typically used discrete button pressing
12 tasks to record RT and assess orienting of attention. However, it is of interest to investigate
13 social cues from an action-oriented approach because human behaviour requires interaction with
14 objects in the environment via reaching, grasping, and manipulation actions. Further, the
15 recording and analysis of reaching movements provides additional variables and measures which
16 may generate deeper insights into cognitive processes. Deviations in an individual's upper limb
17 trajectory towards or away from non-target stimuli while reaching towards a target may give an
18 index of the locus of attention and the dynamics of the continuous processing of information
19 (Gallivan & Chapman, 2014; Song & Nakayama, 2009); and in particular the coupling between
20 action and attention (see Welsh & Weeks, 2010, for review). Thus, it has become evident that
21 investigating changes in the spatial and temporal characteristics of motor responses may provide
22 new and nuanced insight into the dynamics of the cognitive mechanisms that enable complex
23 behaviour. Further, examining the trajectories of reaching movements can provide information

1 on ongoing cognitive mechanisms (see also Chapman et al., 2010; Gallivan & Chapman, 2014;
2 Moher & Song, 2013; Welsh & Elliott, 2004).

3 Though attention and action may be tightly coupled (see Welsh, 2011), there may be
4 differences in how the relevant orienting and prioritization mechanisms temporally propagate
5 throughout attentional and motor networks. In work concerning the processing of non-predictive
6 peripheral cues, Neyedli and Welsh (2012) mapped the time-course of facilitation and inhibition
7 following the onset of an attention-capturing peripheral cue in a reaching task. Participants
8 executed aiming movements to targets presented at one of three potential locations 100, 350,
9 850, or 1100 ms after the onset of a non-predictive peripheral cue (a 50 ms “flash”) at one of the
10 potential target locations. The time-course of RTs to cued and uncued targets was similar to the
11 previously described time-course in traditional peripheral cuing tasks wherein IOR emerges;
12 participants had significantly shorter RTs to uncued targets than to cued targets at SOAs of 350
13 ms, 850 ms and 1100 ms. No facilitation effect at 100 ms, however, was observed for RTs. The
14 pattern of trajectory deviations differed slightly from this RT pattern. Specifically, even though
15 no facilitation was observed and an inhibitory influence on RT was observed at 350 ms and later,
16 movement trajectories deviated towards cued locations at SOAs lower than 350 ms (revealing a
17 facilitation effect associated with the response to the cue) and then deviated away from cued
18 locations at the larger SOAs of 850 and 1000 ms (revealing an inhibition effect associated with
19 the response to the cue). These data indicate that the mechanisms that generate “attentional”
20 facilitation and inhibition are represented in the motor system and influence the execution of
21 action, but that motoric facilitation (presence of a competing response) lasted longer and motoric
22 inhibition (inhibition of that competing response) was relatively delayed when compared to
23 manifestation of facilitation and inhibition in RTs. This pattern of RTs and trajectory effects was

1 replicated in a further study with smaller increments between SOAs (Welsh, Neyedli, &
2 Tremblay, 2013). Consequently, it is possible that different behavioural expressions of
3 facilitation and inhibition are seen in RTs and in measures of trajectory deviation. As such,
4 kinematic analyses of reaching movements can provide new insights into the sensorimotor
5 systems involved in the processing of different types of stimuli. For this reason, investigating
6 attention orienting cues with upper-limb reaching movements can clearly provide additional
7 insight into the associated neural mechanisms.

8 **The Present Experiments**

9 The purpose of the current experiments was to examine the mechanisms underlying the
10 processing of social cues (gaze and pointing) by examining the influences of these cues on the
11 spatial and temporal characteristics of upper-limb reaching movements. Three experiments are
12 reported herein. Experiments 1 and 2 concern gaze cues and Experiment 3 concerns finger
13 pointing cues. We predict several patterns of data based on the premise that social cues engage
14 attentional mechanisms and these attentional mechanisms are linked to and exert an influence on
15 the motor system (as in Welsh, 2011, for example). If social cues engage mechanisms that are
16 similar to those engaged with the bottom-up processing of peripheral cues, then patterns of RTs
17 and movement trajectory deviations, and dissociations between the two behavioural effects,
18 similar to those observed in Neyedli and Welsh (2012) may be observed here. Specifically, it
19 was predicted that RTs may be shorter to cued than to uncued targets at short SOAs, and
20 trajectories to uncued targets will deviate towards the cued location at short SOAs. Predictions
21 regarding deviations towards or away from the cued location at longer SOAs were unclear given
22 the previously observed differences in the emergence of the spatial and temporal effect at longer
23 SOAs (Neyedli & Welsh, 2012). Indeed, it even was possible that inhibitory mechanisms may

1 work in the motor system while excitatory mechanisms operate in attention. On the other hand, if
2 attentional shifts following social cues do not drive response producing processes to interact with
3 the object at the cued location, then even though there still may be cuing effects in RTs, the
4 trajectories of movements to uncued and cued target locations will not differ.

5 **Experiment 1**

6 Participants in Experiment 1 completed aiming movements to targets that appeared
7 randomly at a left or right target location. A gaze cue preceded the onset of the target by SOAs
8 varying between 100 and 2400 ms. Based on previous research, it was predicted that RTs would
9 be shorter to cued targets than uncued targets at most SOAs. It is possible, though unlikely, that
10 RTs to cued targets may be longer than to uncued targets at the longest SOA because the gaze
11 cue in this experiment remained fixed on the potential target location throughout a given trial
12 (see Frischen & Tipper, 2004). The pattern of trajectory deviations of the hand movements to the
13 target will depend on the relationship between attention and action systems and the mechanisms
14 that generate the changes in RTs following gaze cues. Although it is unlikely for IOR to emerge
15 in RTs, it is possible that such effects of inhibition may be detected in the trajectory deviations as
16 a dissociation between these behavioural effects has previously been shown (e.g. Neyedli &
17 Welsh, 2012; Welsh et al., 2013).

18 **Methods**

19 **Participants.** Twenty participants (15 women, 5 men) aged nineteen to thirty-seven years
20 (mean age = 26 years) were recruited from the University of Toronto community. All
21 participants were right-hand dominant and had normal or corrected to normal vision. Participants
22 provided full and informed consent and they were monetarily compensated for their time. All

1 procedures were approved and were consistent with the standards put forth by the University of
2 Toronto Research Ethics Board.

3 **Apparatus.** Participants sat comfortably in front of a 24-inch widescreen monitor (Acer
4 GD235HZ) with a resolution of 1920 (w) by 1080 (h) pixels. The monitor was angled
5 approximately 20 degrees from the surface of the table. The initial display included a home
6 position (a blue circle 1.5 cm in diameter) located 1 cm above the bottom of the screen, and two
7 open blue square target placeholders (2 cm) that were located approximately 28 cm horizontally
8 from one another and 25 cm diagonally from the home position. The cue stimulus was the image
9 of a young adult male face, whose gaze (face and eyes) was initially directed centrally towards
10 the participant. The face measured approximately 6 cm (w) and 8 cm (h) and was centred
11 between the two target placeholders. The eye-gaze cue consisted of an image of the same male
12 with the iris and pupils displaced to the left or right. All images were presented on a light grey
13 background. Throughout the experiment, participants were in view of an optoelectric motion
14 tracking system (Optotrack, Northern Digital Inc., Waterloo, Ontario, Canada). An infrared
15 emitting diode (IRED) was attached to the participants' right index fingers and the motion of this
16 IRED was recorded at a rate of 250 Hz for 1500 ms, starting at the onset of the target.

17 **Task and procedure.** In a given trial, a participant would begin with his or her right
18 index finger on the home position. After 1000 ms the eyes of the face presented in the visual
19 display would shift towards the left or right target placeholder, providing a non-predictive gaze
20 cue (see Figure 1 for a schematic depiction of the time-course of a given trial). After a variable
21 SOA (100, 250, 400, 700, 1000, 1700, and 2400 ms), one of the target placeholders would
22 become solid, signalling the participant to move their index finger from the home position to the
23 given target placeholder as soon as possible. We used a relatively long range of SOAs to assess

1 the time-course of facilitation and potential inhibition (as it was at these longer SOAs that IOR
2 for gaze cues was observed by Frischen & Tipper, 2004).

3 The participant's movements were recorded for 1500 ms after which the display would
4 reset to the initial display and the participant could initiate another trial by placing his or her
5 finger in the home position. Participants were instructed to move towards and touch the target
6 location as soon as they saw one of the target placeholders become solid. They were informed
7 that the preceding gaze cue was entirely non-predictive (i.e., that the target would appear on both
8 the left and right side equally and randomly, and the cue and SOA were presented randomly with
9 respect to the target). The target could be presented either at the cued (i.e., in the location
10 specified by the cue) or uncued (i.e., in the direction opposite the cue) location. Fifteen cued and
11 uncued trials were performed for both the left and right target placeholder at each of the seven
12 SOAs for a total 420 experimental trials. Trial types were randomly distributed throughout the
13 experiment and were broken up into five blocks of eighty-four trials with self-paced breaks in
14 between each block. Prior to the experimental trials, participants executed fourteen practice
15 trials. The total time in testing was approximately 1 hour.

16 **Data reduction and analysis.** The data were stored for offline analysis using a custom
17 analysis program to calculate kinematic data using Matlab (The Mathworks Inc.). IRED position
18 data were filtered using a second order dual pass Butterworth filter with a low-pass cut-off
19 frequency of 10Hz. The position data were then differentiated to obtain instantaneous velocity of
20 the movement. The start and the end of the movement were identified as the first sample in
21 which instantaneous velocity in the z-axis (vertical axis) surpassed and fell below 50mm/s for
22 three consecutive samples, respectively. Each trial was visually inspected. If this criteria did not
23 isolate the start and end of the movement properly (for example, due to the participant making

1 unnecessary movement at the home or end position), the start and end of movement was
2 determined visually. Reaction time (RT) was defined as the time from target onset to the
3 calculated movement start. Movement time (MT) was defined as the time from the calculated
4 movement start to the calculated movement end.

5 ***Calculation of initial movement angle.*** Initial movement angle for a given trial was
6 calculated to provide an index of the initial curvature or direction of a participant's movement.
7 This measure was calculated by finding the absolute angle in degrees between the y axis, and the
8 line created from the (x,y) coordinates of their starting position and the (x,y) coordinates of the
9 participant's position at 20% of their movement trajectory. This measure was chosen because it
10 represented a point in the movement trajectory that best represented the initial representations of
11 action in the motor system because it was early enough such that the trajectory was not likely
12 subject to online corrective processes based on visual information (Elliott et al., 2010; see
13 Footnote 1).

14 ***Outlier analysis.*** Thirty-five trials across all participants (0.4% of all data) were removed
15 prior to analysis for obvious recording and/or experimental error. Trials in which a participant's
16 RT was less than 100 ms or greater than 1000 ms as well as trials in which MT was greater than
17 1000ms were removed from the analysis (0.1% of all data). Following these initial screenings,
18 trials in which RT fell outside of 2.5 standard deviations for each participant and condition were
19 removed from the analysis (2% of all data). Overall, 2.6% of the entire data set was excluded
20 from analysis.

21 ***Statistical analysis.*** A 2 (Target: cued, uncued) X 7 (SOA: 100, 250, 400, 700, 1000,
22 1700, 2400 ms) repeated measures ANOVA was conducted on each of the three dependent
23 measures: RT, MT and IMA. For each of these analyses, where Mauchly's test of sphericity

1 indicated that the assumption of sphericity was violated, Hyun-Feldt corrected values are
2 reported (indicated by degrees of freedom with decimals). Where a significant interaction was
3 found, planned comparisons were conducted to determine differences between cued and uncued
4 trials at each of the seven SOAs.

5 **Results**

6 **Reaction time.** Significant main effects for Target, $F(1,19) = 42.97, p < .001, \eta_p^2 = .69$
7 and SOA, $F(3.19, 60.63) = 10.32, p < .001, \eta_p^2 = .35$ were found (Figure 4, top left). The main
8 effect for Target revealed that RTs on cued target trials ($M = 299$ ms, $SD = 46.98$) were shorter
9 than those on uncued target trials ($M = 310$ ms, $SD = 48.46$). For the main effect of SOA,
10 examination of the RT data presented in Figure 4 suggest that RTs were longer at shorter SOAs
11 and generally decreased as SOA increased – consistent with this observation, there was a
12 significant linear trend, $F(1,19) = 17.07, p < .01, \eta_p^2 = .47$. There was no significant Target by
13 SOA interaction, $F(6,114) = 1.78, p = .11, \eta_p^2 = .09$. This result indicates that there were no
14 statistical differences in the cuing effect that emerged across the seven SOAs, and in particular
15 no evidence of IOR at the long SOAs.

16 **Movement time.** There were no significant main effects of Target, $F(1,19) = 1.42, p =$
17 $.25, \eta_p^2 = .07$, or SOA, $F(4.75, 90.26) = 1.02, p = .41, \eta_p^2 = .05$, and no significant interaction
18 between Target and SOA, $F(6,114) = 1.35, p = .24, \eta_p^2 = .07$. Consequently, it is clear that
19 neither the cue nor SOA had any significant effect on MT.

20 **Initial movement angle.** There were no significant main effects of Target, $F(1,19) =$
21 $.001, p = .98, \eta_p^2 < .001$, or SOA, $F(4.46, 5.90) = 2.26, p = .06, \eta_p^2 = .10$, and no significant
22 interactions between the two factors, $F(4.55, 86.35) = 1.81, p = .12, \eta_p^2 = .09$ (Figure 4, top
23 right). Therefore, neither cue nor SOA had a significant effect on IMA in this experiment.

1 Experiment 2 was designed and conducted to further address the processing of gaze cues
2 because the results of Experiment 1 were not entirely consistent with the findings of previous
3 work on cuing effects in two main ways. First and foremost, although facilitatory cuing effects
4 were present in RTs, there were no differences in the trajectories of the executed aiming
5 movements. This distinction between the presence of cuing effects in RTs and the absence of
6 cuing effects in trajectories is not consistent with a series of studies revealing cuing effects in
7 both RTs and trajectories when peripheral cues are used (e.g., Lee, 1999; Neyedli & Welsh,
8 2012; Welsh, 2011; Welsh et al., 2013). Thus, the data from Experiment 1 suggest that gaze cues
9 may not activate responses in the same way as peripheral cues. Given this unexpected result,
10 Experiment 2 was conducted to provide an additional testing of the prediction that response
11 codes will be activated following the shift of attention generated by gaze cues.

12 Second, the gaze cues in Experiment 1 led to a somewhat different pattern of RTs from
13 those revealed in previous studies of gaze cues. Specifically, there was an overall facilitation
14 effect associated with the cue in RTs, and this effect was not significantly different across SOAs.
15 This latter RT effect is not entirely consistent with, for example, the results of the study by
16 Frischen and Tipper (2004) who demonstrated that no cueing effects were present at the 1200 ms
17 SOA. It is possible that the chosen methodology may account for the discrepancy in results. In
18 Experiment 1 reported herein, the central face remained gazing towards the placeholder
19 throughout the longest SOA period. In the Frischen and Tipper (2004) study, the greatest
20 changes across SOA were found when the methodology increased the potential that attention
21 would be removed from the cued peripheral target. For instance, IOR emerged at the long SOA
22 when the central face with the gaze cue was masked with a fixation cross before the presentation
23 of the target because it is likely that the mask and disappearance of the gaze cue disengages

1 attention from the cued location (and presumably reengages attention centrally). Thus, it is likely
2 that sustained cuing effects in Experiment 1 were due to the continued orientation of the central
3 gaze cue to one of the target locations. It is possible that the chosen methodology also failed to
4 engage the response-producing processes in the motor system which in turn led to the non-effects
5 of cue on movement trajectories (see previous paragraph). Therefore, the gaze of the face in
6 Experiment 2 returned to a neutral position (i.e., direct gaze at the participant) 150 ms after the
7 initial presentation of the gaze cue towards one of the cued locations. This return of gaze to the
8 central location may have the effect of disengaging attention from the peripheral location and
9 drawing it back to central fixation (Böckler, van der Wel, & Welsh, 2014, 2015). All other
10 aspects of the experiment remained identical to Experiment 1.

11 **Methods**

12 **Participants.** Twenty participants (15 women, 5 men) aged eighteen to thirty years
13 (mean age = 23.5 years) were recruited from the University of Toronto community. All
14 participants were right handed and had normal or corrected to normal vision. Participants
15 provided full and informed consent and were monetarily compensated for their time. All
16 procedures were approved and were consistent with the standards put forth by the University of
17 Toronto Research Ethics Board. Prior to analysis, four participants were removed due to
18 technical difficulties that resulted in improper recording of the data.

19 **Apparatus.** The apparatus and experimental set up were identical to that of Experiment
20 1. All display and movement recording properties were consistent across the two experiments.

21 **Task and procedure.** The task, timing of the stimuli, and procedure were identical to
22 Experiment 1 except that the gaze of the model in central fixation would shift back to the center

1 neutral position 150 ms after it shifted to the periphery (see Figure 2 for a schematic depiction of
2 the time-course of an individual trial).

3 **Data reduction and analysis.** The data were processed and analyzed in a similar manner
4 to Experiment 1. Sixty-two (62) trials across all participants (1% of all data) were removed prior
5 to analysis for obvious recording and/or experimental errors. As in Experiment 1, trials in which
6 a participant's RT was less than 100 ms or greater than 1000 ms as well as trials in which MT
7 was greater than 1000ms were removed from the analysis (0.2% of all data). Following this
8 initial screening, trials in which RT fell outside of 2.5 standard deviations for each condition
9 within a participant's responses were removed from the analysis (2.3% of all data). All together,
10 3.5% of the data set was excluded from statistical analysis. One participant's mean MTs were
11 longer than 2.5 SDs of the mean MT for the group as a whole. For this reason, this participant
12 was removed for moving too slowly and not following instructions. Thus, the final sample size
13 was 15 for Experiment 2. Statistical analyses followed those outlined in Experiment 1.

14 **Results**

15 **Reaction time.** Significant main effects for Target, $F(1,14) = 9.50, p < .01, \eta_p^2 = .40$, and
16 SOA, $F(4.85, 67.99) = 21.78, p < .001, \eta_p^2 = .61$ were found. The main effect of Target revealed
17 that RTs to cued targets ($M = 264$ ms, $SD = 33.44$) were shorter than those to uncued targets (M
18 $= 271$ ms, $SD = 30.69$). For the main effect of SOA, there was a significant linear trend, $F(1,14)$
19 $= 35.29, p < .001, \eta_p^2 = .72$, revealing that RTs generally increased as a function of SOA. There
20 was also a significant Target by SOA interaction, $F(6, 84) = 3.18, p < .01, \eta_p^2 = .19$ (Figure 4,
21 center left). Planned comparisons revealed that RTs in reaches to cued targets were significantly
22 shorter than in reaches to uncued targets at the 250 ms, $t(14) = 5.0, p < .001, 95\% \text{ CI } [-26.07, -$
23 $7.20], d_z = 1.29$, 400 ms, $t(14) = 2.47, p < .05, 95\% \text{ CI } [-15.01, -1.07], d_z = 0.64$, 700 ms, $t(14) =$

1 2.13, $p < .05$, 95% CI [-17.47, -0.68], $d_z = 0.59$, and 1000 ms SOAs, $t(14) = 2.74$, $p < .05$, 95%
2 CI [-12.18, -1.9], $d_z = 0.71$. There were no other statistically significant differences ($p > .05$)
3 between cued and uncued targets at the remaining SOAs (i.e., 100 ms, 1700 ms, and 2400 ms).
4 Therefore, it appears that there were facilitation effects of cue at shorter SOAs (with the
5 exception of the 100 ms SOA) that dissipated at SOAs longer than 1000 ms. No evidence of IOR
6 was observed.

7 **Movement time.** No effect of Target was detected, $F(1,14) = 0.84$, $p = .38$, $\eta_p^2 = .06$, or
8 SOA, $F(6,84) = 1.35$, $p = .09$, $\eta_p^2 = .09$. There was also no significant interaction between Target
9 and SOA, $F(6,84) = .35$, $p = .91$, $\eta_p^2 = .02$. Therefore, neither the cue nor SOA had a significant
10 effect on MT in this experiment.

11 **Initial movement angle.** No significant main effect of Target, $F(1,14) = .46$, $p = .51$, η_p^2
12 = .03, or Target by SOA interaction, $F(6,84) = .30$, $p = .94$, $\eta_p^2 = .02$, was found. There was,
13 however, a significant main effect of SOA, $F(6,84) = 2.64$, $p < .05$, $\eta_p^2 = .16$ (Figure 4, center
14 right). Accordingly, there was a significant linear trend for SOA, $F(1,14) = 13.32$, $p < .01$, $\eta_p^2 =$
15 .49, revealing that IMAs generally increased as SOA increased. Overall, and consistent with
16 Experiment 1, there was no difference in IMA between reaches to cued and uncued targets.

17 Discussion

18 Experiment 2 differed from Experiment 1 in that the gaze cue did not remain fixed on a
19 given target. Following 150ms, the direction of the gaze cue returned from one of the
20 placeholders to the center neutral position and was oriented towards the participant. A different
21 pattern of RTs emerged in Experiment 2 from that in Experiment 1. Of particular interest is the
22 significant Target by SOA interaction for RT. Planned comparisons demonstrated that this
23 interaction was driven by a facilitation associated with the cue at SOAs 250-1000 ms that

1 coupling, and how eye gaze tends to proceed the hand to the object with which the individual
2 will interact (see Flanagan & Johansson, 2003).

3 Experiment 3 was conducted to investigate whether or not a social cue that might be
4 more tightly linked to the manual motor system (e.g., a pointing finger) affects the spatio-
5 temporal characteristics of goal-directed movements. Although finger pointing may be social and
6 communicative in a manner similar to eye gaze, the observation of a pointing finger may engage
7 the neural action codes associated with pointing in the observer – e.g., the action observation
8 (putative mirror neuron system; see Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Rizzolatti &
9 Craighero, 2004). This alternate social cue may then be more closely linked to the reaching or
10 pointing movements employed in the present tasks, leading to a stronger propensity to generate
11 competing response codes that would lead to larger deviations in the trajectory of the
12 participants' hand movements. Indeed, trajectory deviations in reaching movements executed in
13 a Simon effect task have previously been reported when a hand with a pointed finger was used as
14 the stimuli (Welsh, Pacione, Neyedli, Ray, & Ou, 2015). If all social cues affect response
15 initiation processes, but not response planning and execution, then the same pattern of cuing
16 effects in RTs but not IMA that was observed in Experiments 1 and 2 will be observed in
17 Experiment 3. If, on the other hand, a finger pointing towards a target is more closely coupled
18 with the reaching movement being performed, then perhaps RT effects and trajectory deviations
19 will be observed in Experiment 3. It was predicted, therefore, that trajectory deviations would
20 differ more between cued and uncued targets in this experiment.

21 **Methods**

22 **Participants.** Twenty participants (11 women, 8 men, the age and gender data for one
23 participant are not reported) aged eighteen to thirty three years (mean age = 22.6 years) were

1 recruited from the University of Toronto community. All participants were right handed and had
2 normal or corrected to normal vision. Participants provided full and informed consent and were
3 financially compensated for their time. All procedures were approved by and were consistent
4 with the standards put forth by the University of Toronto Research Ethics Board. The data set
5 from one participant was removed prior to analysis due to a technical difficulty that resulted in
6 improper recording of the data.

7 **Apparatus.** The apparatus and experimental set up were identical to that of Experiments
8 1 and 2. Recording properties were consistent across the three experiments. The display of the
9 home position and target placeholders was identical to those of Experiments 1 and 2. The
10 centrally presented images consisted of the hand of a Caucasian individual pointing at the
11 participant or at one of the two target locations. The central pointing image measured
12 approximately 7 cm (w) by 6.5 cm (h) and were centred between the two target placeholders.

13 **Task and procedure.** The trial procedures for Experiment 3 were identical to those of
14 Experiment 1, except for the stimulus that was used. The left and right pointing finger images
15 measured approximately 12 cm (w) by 6.5 cm (h). As in Experiment 1, the pointed finger cue
16 remained fixed towards the given target placeholder throughout the trial (see Figure 3 for a
17 schematic depiction of the time-course of a given trial). After a variable SOA, one of the target
18 placeholders became solid, signalling the participant to place their index finger in the given
19 target placeholder. The same seven SOAs were used: 100, 250, 400, 700, 1000, 1700, and 2400
20 ms. Fifteen cued and uncued trials were performed for both the left and right target placeholder
21 at each of the seven SOAs (total trials = 420).

22 **Data reduction and analysis.** Two-hundred and twenty-five trials across all participants
23 (2.8% of all data) were removed prior to analysis for obvious recording and/or experimental

1 error. The start and the end of the movement were determined in the same manner as in the
2 previous experiments. As in the previous experiments, trials in which a participant's RT was less
3 than 100 ms or greater than 1000 ms as well as trials in which MT was greater than 1000ms were
4 removed from the analysis (0.14% of all trials). Following this initial screening, trials in which
5 RT fell outside of 2.5 standard deviations for each participant and condition were removed from
6 the analysis (2.32% of all trials). Statistical analysis was the same as outlined in Experiment 1.

7 **Results**

8 **Reaction time.** There was a significant effect of Target, $F(1,18) = 6.29, p < .05, \eta_p^2 =$
9 $.26$, and a significant Target by SOA interaction, $F(6,108) = 10.43, p < .001, \eta_p^2 = .37$ (Figure 4,
10 bottom left). The main effect of Target revealed that RTs to cued targets ($M = 344$ ms, $SD =$
11 48.91) were shorter than those to uncued targets ($M = 354$ ms, $SD = 52.95$). There was no
12 significant main effect of SOA, $F(6,108) = 1.83, p = .10, \eta_p^2 = 0.09$. Planned comparisons
13 revealed that RTs in reaches to cued targets were significantly shorter than in reaches to uncued
14 targets at SOAs of 100 ms, $t(18) = 4.17, p < .01, 95\% \text{ CI } [-41.29, -13.61], d_z = 0.96$, and 250 ms,
15 $t(18) = 5.04, p < .001, 95\% \text{ CI } [-47.43, -19.42], d_z = 1.16$. No other statistically significant cued
16 vs uncued target RT differences emerged across the other SOAs ($p > 0.05$).

17 **Movement time.** There were no significant effects of Target, $F(1,18) = .023, p = .88, \eta_p^2$
18 $= .001$, or SOA, $F(6,108) = 1.07, p = .29, \eta_p^2 = .06$, and no significant interaction between the
19 two factors, $F(6,108) = .044, p = .85, \eta_p^2 = .02$. Therefore, there was no effect of either cue or
20 SOA on MT.

21 **Initial movement angle.** Significant main effects of Target, $F(1,18) = 5.37, p < .05, \eta_p^2 =$
22 $.23$, and SOA, $F(6,108) = 2.91, p < .05, \eta_p^2 = .14$, were found. There was, however, no Target by
23 SOA interaction, $F(4.46,80.36) = .47, p = .79, \eta_p^2 = .03$ (Figure 4, bottom right). The main effect

1 of Target indicated that IMAs in reaches to uncued targets were smaller (i.e., more central, $M =$
2 26.22, $SD = 5.18$) than IMAs in reaches to cued targets overall ($M = 27.02$, $SD = 5.69$). That is,
3 the movements to locations that were not cued (not pointed at) deviated towards the cued
4 (pointed at) location.

5 **Between experiment analysis.** To assess any potential significant differences in
6 trajectory deviations to cued and uncued targets between gaze and pointing cues, the IMA data
7 from the two experiments with the most similar designs were analyzed using a 2 (Target: Cued,
8 Uncued) by 6 (SOA: 100, 250, 400, 700, 1000, 1700, 2400) by 2 (Experiment: 1, 3) mixed
9 ANOVA with Experiment as a between group factor and SOA and Target as within-subjects
10 factors. There was no significant main effect of SOA, $F(6,222) = 1.29$, $p = .26$, $\eta_p^2 = .03$, and no
11 significant interactions between Target and SOA, $F(6,222) = 0.20$, $p = .98$, $\eta_p^2 = .005$, or Target,
12 SOA, and Experiment, $F(6,222) = 1.56$, $p = .16$, $\eta_p^2 = .04$. There was however, a significant SOA
13 by Experiment interaction, $F(6,222)$, $p < .001$, $\eta_p^2 = .10$, suggesting that the pattern of IMAs
14 across SOAs varied differently between the two experiments. The main effect of Target
15 approached but did not reach conventional levels of statistical significance, $F(1,37) = 3.67$, $p =$
16 $.06$, $\eta_p^2 = .09$. Likewise, the critical interaction between Target by Experiment interaction
17 approached, but did not surpass, conventional levels of statistical significance, $F = 3.79$, $p = .06$,
18 $\eta_p^2 = .09$.

19 **Discussion**

20 Experiment 3 explored the mechanisms of social cueing activated when a cue that more
21 closely matched the response was presented. The finger-pointing cue used in this experiment
22 generated a short-lived facilitatory cuing effect in RTs. Unlike in Experiments 1 and 2, however,
23 significant effects of cue were now also detected in the initial angle of the movement trajectory.

1 The between experiment analysis suggested that the difference in IMA between cued and uncued
2 targets tended to be larger in Experiment 3 than in Experiment 1, though this difference was not
3 statistically significant. Overall, the results of Experiment 3 suggest that when the social cue
4 (i.e., pointing, in this case) presented more closely matched the response being generated, reach
5 trajectories were more likely to be affected.

6 **General Discussion**

7 The aim of the three present experiments was to investigate the mechanisms of social
8 cueing by assessing the time course of facilitation and potential inhibition in social gaze and
9 finger cueing using an upper-limb reaching task. These experiments were grounded in action-
10 centred theories of attention (Song & Nakayama, 2009; Tipper et al., 1992; Welsh & Weeks,
11 2010) and previous work showing that the trajectories of limb movements to targets are affected
12 by the attentional mechanisms activated by a preceding cue (Lee, 1999; Welsh, 2011; Welsh et
13 al., 2013). As such, the temporal and kinematic characteristics of upper-limb reaching
14 movements were analyzed to determine the linked attentional and motoric components of
15 facilitation and inhibition in each of the cuing paradigms. Although the analyses of the RTs in
16 each of the experiments were consistent with previous findings related to gaze cuing and
17 generally revealed facilitatory effects of the social cues, the critical findings were that no
18 differences in initial movement trajectory were found between reaches to cued and uncued
19 targets following gaze cues (Experiments 1 and 2). Conversely, there was a significant effect of
20 the cue on the reach trajectories of participants when a pointed finger was used as the cue
21 (Experiment 3). Consequently, the data seem to indicate that task specificity and perception-
22 action coupling (i.e., a direct match in effector, in this case) may play a role in the processing of
23 these cues and, as a result, their subsequent effects on action initiation and execution.

1 To address the main purpose of the experiments, the present data are consistent with the
2 idea that the mechanisms underlying gaze cues are different from those that lead to stimulus-
3 driven attentional shifts following peripheral cues. This conclusion is based on a comparison
4 between the results of Experiments 1 and 2 and a series of previous studies in which participants
5 complete aiming movements to targets following dynamic peripheral cues (e.g., Lee, 1999;
6 Neyedli & Welsh, 2012; Welsh, 2011; Welsh et al., 2013). In Experiments 1 and 2, clear
7 facilitatory effects associated with the social gaze cue were observed in response initiation times
8 (RTs), but there was no evidence of any manifestation of facilitation (or inhibition) in the
9 movement trajectories. This pair of findings stands in contrast to the results of numerous studies
10 that have provided evidence of excitatory and inhibitory mechanisms expressed in *both* RT and
11 movement trajectories in studies employing peripheral cues to evoke stimulus-driven captures of
12 attention (e.g., Welsh, 2011; Welsh et al., 2013). It has been previously suggested that, because
13 of the tight coupling of attention and action processes, the dedication of attention to a specific
14 location or object activates processes to produce a response to interact with that location (Tipper
15 et al., 1992; Welsh & Weeks, 2010). Thus, the absence of such a tight coupling between
16 attention and action production following gaze cues suggests that the shifts of attention following
17 gaze cues and dynamic peripheral cues are likely to be generated by different mechanisms.
18 Similar conclusions regarding the potential for independent processing channels for social (gaze)
19 and non-social (motion) cues have been previously made (Böckler et al., 2014, 2015).

20 Conclusions regarding the (dis)similarity of the mechanisms underlying gaze and central
21 symbolic cues are more difficult to draw because there is no study that we are aware of that has
22 directly examined the pattern of RTs and trajectory deviations that emerge following non-
23 predictive centrally-presented symbolic cues such as arrows. Nonetheless, there is evidence from

1 studies involving keypress tasks that social gaze cues are processed differently from centrally-
2 presented arrow cues (Marotta, Lupiáñez, Martella, & Casagrande, 2012; Marotta, Román-
3 Caballero, & Lupiáñez, 2018). Further, there is a contrast between the results of Experiments 1
4 and 2 in which no trajectory deviations were observed following gaze cues, and Experiment 3 in
5 which a centrally-presented pointing finger generated facilitatory effects in RT and trajectory
6 deviations. In this sense, not all social cues influence the attention and action system in the same
7 way. As such, social cues (and indeed, non-social centrally-presented cues) should not be taken
8 as one and the same and nuanced explorations of cueing effects are required (see Atkinson,
9 Simpson, & Cole, 2018 for a review and discussion).

10 As already suggested, the trajectory deviations in the pointing cue task may have emerged
11 because of a match between the cue and the effector that the participant used for the task.
12 Previous work has demonstrated that the relationship between the characteristics of the target
13 and non-target stimuli and the type of response that will be executed can have an influence on
14 the interference caused by distractors. For instance, Welsh and Pratt (2008; see also Welsh &
15 Zbinden, 2009) demonstrated that offset distractors caused interference in responding to an onset
16 target in a key press task, but not in an upper-limb aiming task. The authors suggested that this
17 response-related difference in the impact of the offset distractor on an onset target was due to the
18 differences in action affordances of the stimuli between the two tasks. Because the visuomotor
19 system needs a stable source of information about the target to ensure that accurate termination
20 of an aiming movement, an offset stimulus is not salient to the attention/action system because it
21 does not provide that stable source of visual information (there is no longer any stimulus
22 information at the location of an offset). Hence, the offset distractor does not capture attention
23 and cause interference when an aiming movement is executed because it is not salient to the

1 system when an aiming movement is required. In contrast, the attention/action system does not
2 need a stable source of endpoint information to ensure accuracy when discrete button responses
3 are being executed. Hence, any dynamic change in the environment is salient to the visuomotor
4 system and, in this case, offset stimuli can capture attention and cause interference. Similarly,
5 Bekkering and Neggers (2002) found that visual processing of distractor items were different
6 when participants prepared a reach-to-grasp action as compared to a reach-to-point action.
7 Specifically, participants made more saccadic eye movements to a non-target object with the
8 wrong orientation when they reached-to-grasp the target object than when they reached-to-point
9 to the object. When the distractor item was of a different colour, there were no differences
10 between the tasks. Thus, orientation was a salient feature that caused enhanced distraction when
11 performing grasping actions, in which orientation is a key feature. Overall, these studies
12 demonstrate that there is an interaction between response type (i.e., action) and the stimulus
13 characteristics that capture attention.

14 In the context of the present work, it is possible that the nature of the relationship between
15 the characteristics of the upcoming action and those of the stimuli shape processing of the cue
16 stimuli in the current study and influenced the motoric effects of spatial attention. Specifically, it
17 is likely that neural codes for visual perception of the gaze cue and hand cue are coupled with
18 different neural codes for action. There is a great deal of overlap between the neuronal networks
19 active in action observation and those active during action execution (Grèzes & Decety, 2001).
20 This overlap may be rooted in a mirror neuron-like system (MNS) wherein neurons are active for
21 both action perception and execution (Rizzolatti & Craighero, 2004). Consequently, when an
22 action is observed, (e.g., the shift of gaze or the turning of a hand) the perception of this action
23 can in turn activate the neural codes associated with actual performance and control of that

1 action. Perhaps because of the greater overlap in the coding of hand cues and hand actions, the
2 pointed finger led to the activation of a compatible response whereas the eye gaze cue did not.

3 Further, it should be noted that neurophysiological work has demonstrated that eyes (faces)
4 and hands (bodies) are represented and processed in distinct areas of the human cerebral cortex.
5 For instance, areas of the visual cortex have been found to be particularly selective to the
6 perception of faces (e.g., occipital face area [OFA], and fusiform face area [FFA]) while other
7 distinct areas are selective for the perception of bodies, and hands in particular (e.g., the
8 extrastriate body area [EBA], and the fusiform body area [FBA]) (Peelen & Downing, 2007).
9 Additionally, in parietal cortex, the lateral intraparietal area (LIP) is connected with other areas
10 associated with gaze control (e.g., the frontal eye field, and the superior colliculus) whereas the
11 medial intraparietal area (MIP) is more active in reaching movements and is connected with
12 frontal regions that are also associated with reaching (Cisek & Kalaska, 2010). Therefore, it is
13 possible that the different apparent motion cues (i.e., eye gaze shift and hand rotation) used in
14 this experiment were perceived with distinct areas and were then linked with distinct actions and,
15 consequently, control systems.

16 In summary, the current experiments demonstrated that while gaze shifts may facilitate
17 temporal aspects of the initiation of reaching movements such as RT, there is little effect of gaze
18 cueing on the spatial parameters of reaching movements. These data indicate that it is unlikely
19 that a response producing process is activated when a shift of attention has been made to a
20 location following a gaze cue. When the gaze cue was replaced with a finger-pointing cue,
21 however, spatial effects on the movement trajectory were seen, indicating that a response
22 producing process *was* activated following the finger-pointing cue. Overall, this work highlights
23 the important interactions between action systems, cognition, and attention by demonstrating

- 1 how the effector of a social cue (i.e. eye or hand) can influence the spatial characteristics of a
- 2 reaching response.

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Footnote

1. Although the entire movement trajectory was recorded, we chose to analyze movement angle at only one point - 20% of MT (for discussions of techniques that may be used to analyze the whole trajectory, see Gallivan & Chapman, 2014; Lins & Schöner, this issue). This time point of 20% of movement time (which falls approximately at peak acceleration) was chosen because we believe this point (and similar points early in the trajectory) provides an accurate characterization of the movement planning activated by the stimuli at movement initiation. Because the movements in the present study were executed in full vision, time points later in the trajectories may be contaminated by any online correction processes as the movements converge on the target endpoint as the movement unfolds. Hence, the chosen time-point is likely to best represent the simultaneous activation of competing response codes without contamination from online corrections to movement. Although we report only the analysis of this one point, we conducted a subsequent analysis of additional time points (40%, 60%, and 80% of MT) for each experiment. The results of the ANOVAs when all of these time points were included were consistent with the analysis of IMA at only 20% of movement time that is reported in the current paper.

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Open Practices Statement

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None of the data or materials for the experiments reported here is openly available, and

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none of the experiments was preregistered.

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Figures

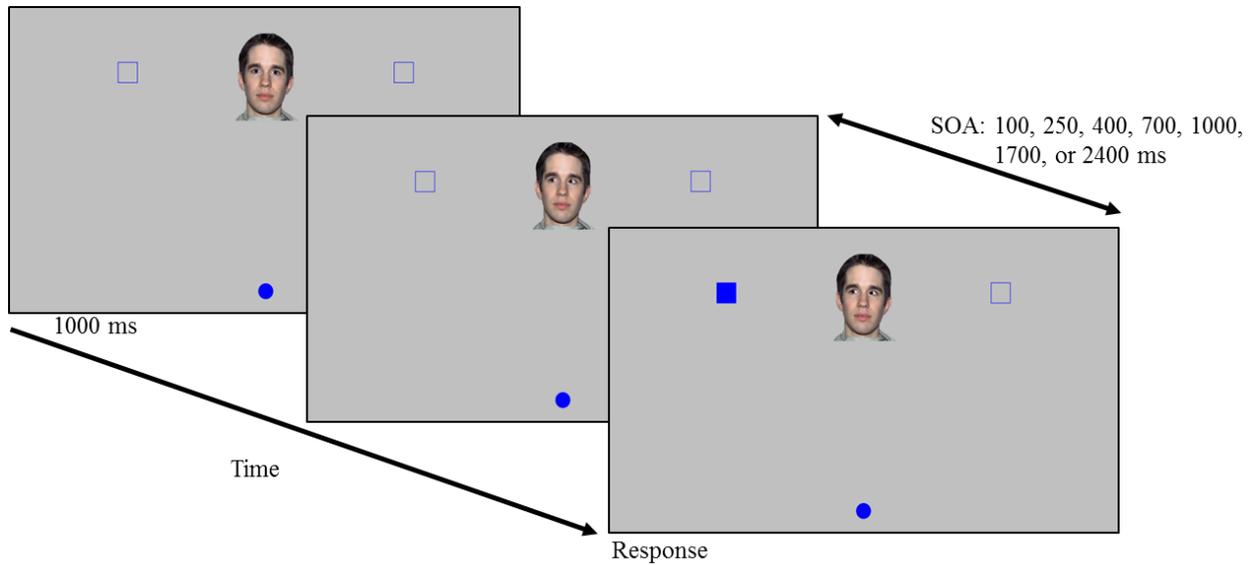


Figure 1. Schematic of the timeline for a given trial. The gaze cue could occur towards the right or left target. The response was to reach out and touch the dark blue target (square).

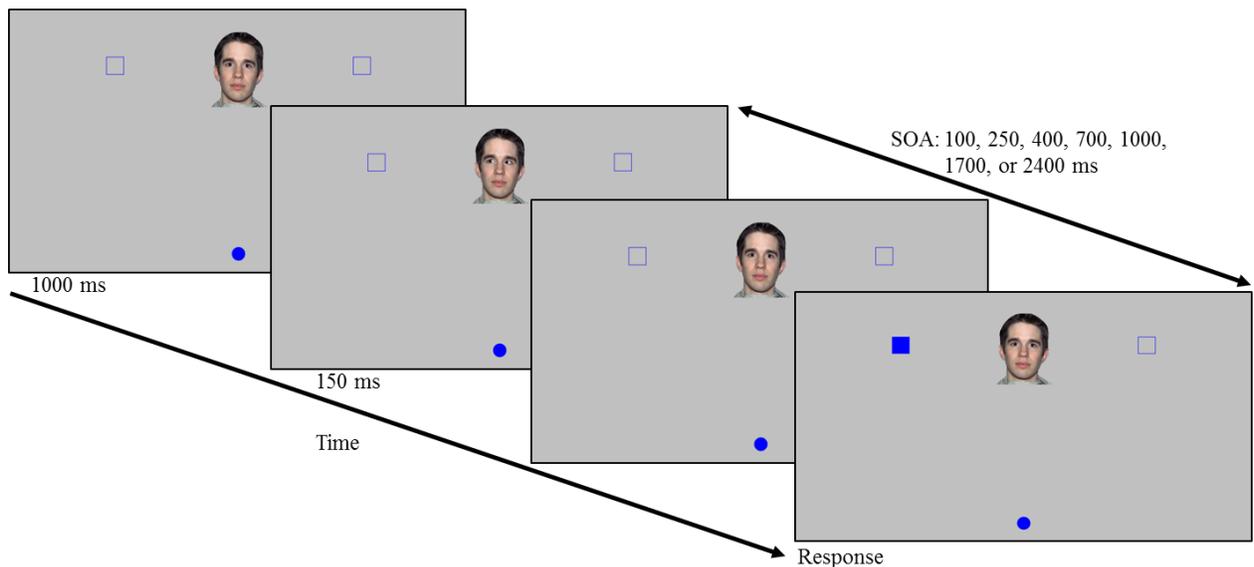


Figure 2. Schematic of the timeline for a given trial. The gaze cue could occur towards the right or left target. The response was to reach out and touch the dark blue target (square).

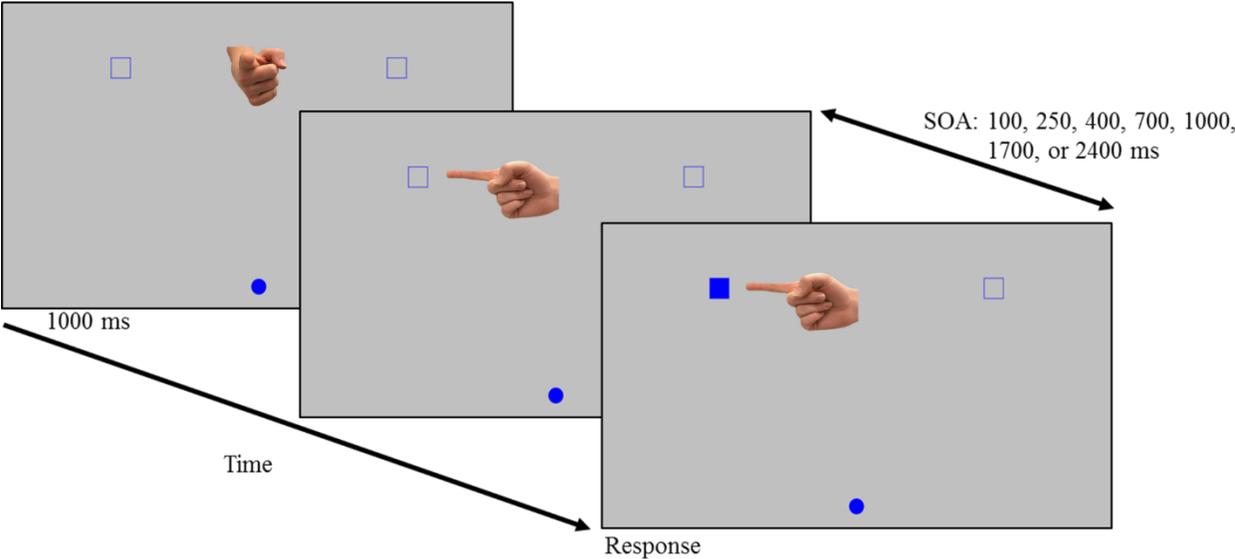
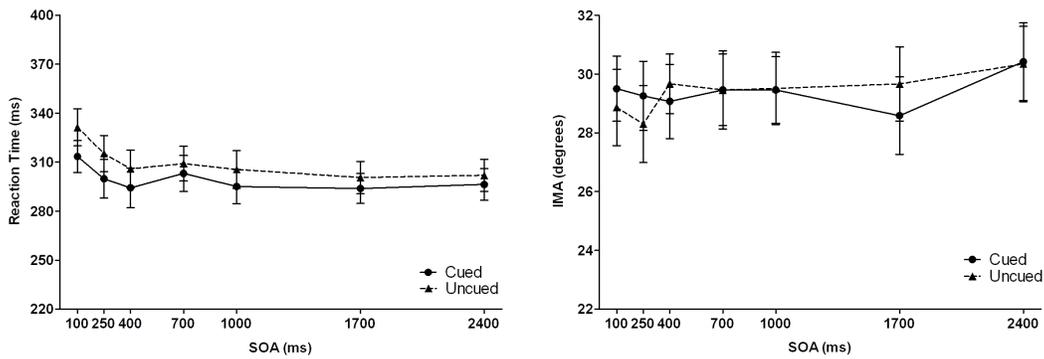
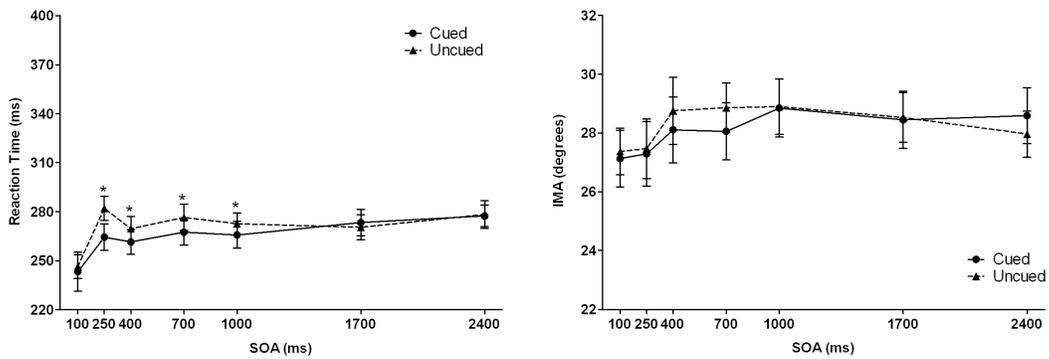


Figure 3. Schematic of the timeline for a given trial. The pointing cue could occur towards the right or left target. The response was to reach out and touch the dark blue target (square).

Experiment 1



Experiment 2



Experiment 3

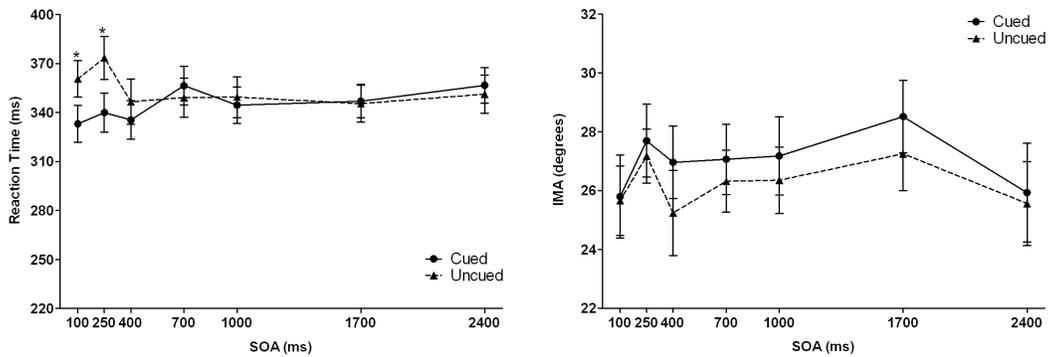


Figure 4. Reaction Time (left side panel) and initial movement angle (IMA, right side panel) for reach of Experiments 1, 2, and 3. Asterisks (*) denote significant differences between cued and uncued trials.