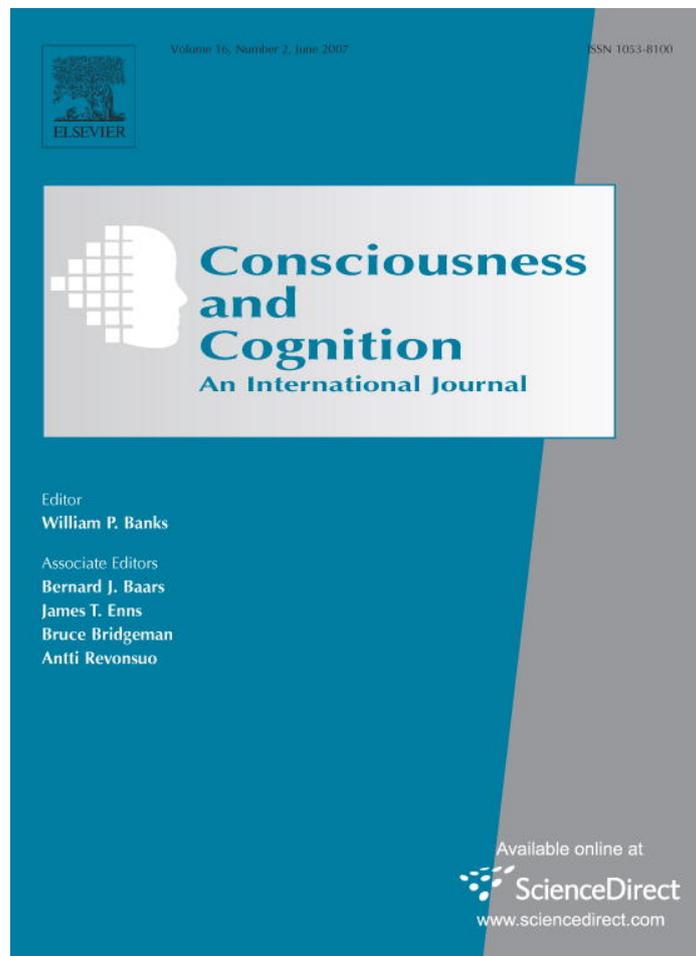


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# On-line control of pointing is modified by unseen visual shapes

Erin K. Cressman, Ian M. Franks, James T. Enns, Romeo Chua \*

University of British Columbia, 210-6081 University Boulevard, Vancouver, BC, Canada V6T 1Z1

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## Abstract

Shapes that are rendered invisible through backward masking are still able to influence motor responses: this is called *masked priming*. Yet it is unknown whether this influence is on the control of ongoing action, or whether it merely influences the initiation of an already-programmed action. We modified a masked priming procedure (Schmidt, 2002) such that the critical prime-mask sequence was displayed during the execution of an already-initiated goal-directed pointing movement. Psychophysical tests of prime visibility indicated that the identity of the prime shapes were not accessible to participants for conscious report. Yet detailed kinematic analysis of the finger in motion revealed that masked primes had an influence on the pointing trajectories within 277 ms of their appearance, 56 ms earlier than the trajectory deviations observed in response to the visible masks. These results indicate that subliminal shapes can indeed influence the control of ongoing motor activity.

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**Keywords:** Masked priming; Response time; Goal-directed action; On-line control

## 1. Introduction

Most of us behave in our everyday life as though our limb actions are under our conscious control at all times. In fact, when brain pathology, trauma, or disease cause limb actions to occur that are not intended, neurologists provide special designations, such as *dystonia* for chronic involuntary movements (Berardelli et al., 1998), *apraxia* for a reduced ability to make voluntary movements (Hermsdorfer, Ulrich, Marquardt, Goldenberg, & Mai, 1999), and *alien hand syndrome* for movements that seem to be controlled by an outside force (Feinberg, Schindler, Flanagan, & Haber, 1992; Parkin & Barry, 1991). Here we examine the possibility that some visually guided actions, even in healthy adults, are controlled by events that are never experienced at a conscious level.

The question of whether visually guided actions can be controlled by events outside of awareness poses a considerable challenge to the researcher. First, an experimental protocol is required in which visual events are presented that, on the one hand, are intense enough to influence brain processes in the participant, but on the

\* Corresponding author. Fax: +1 604 822 6842.

E-mail address: [Romeo.Chua@ubc.ca](mailto:Romeo.Chua@ubc.ca) (R. Chua).

other hand, do not result in explicit awareness of these events. Second, these subliminal events must be shown not only to influence visual processes, but also to influence motor action. Finally, it is not enough to show that motor responses are merely influenced by subliminal events; this could come about by the initiation (priming) of a response that has already been consciously prepared. For example, as a consequence of the instructions provided, an action plan may be established and the participant may use the subliminal information to initiate the preprogrammed response. Thus, to show that visually guided actions can be controlled by subliminal events, it is necessary to show that the priming occurs while motor actions are ongoing. This was the challenge we set for ourselves in the present study.

An established method for presenting subliminal shapes to participants is through the psychophysical procedure of metacontrast masking (for reviews, see [Breitmeyer, 1984](#); [Breitmeyer & Ogmen, 2000](#); [Enns & Di Lollo, 2000](#); [Kahneman, 1968](#)). This is a form of backward masking in which the visibility of a briefly displayed shape (called the *prime*) is greatly reduced when it is followed by another shape that fits snugly around the first shape but does not touch it (called the *mask*). By varying the amount of time that passes between the onset of the prime and the mask, the prime can be rendered invisible to the system responsible for conscious reports and discrimination; prime visibility is typically lowest when the interval is between 40 and 80 ms ([Breitmeyer, 1984](#)). Studies have shown that even under circumstances in which prime shapes cannot be discriminated above a chance level, these unseen prime shapes still influence motor responses that are made to the visible mask that follows in time. Both simple and choice response times to the mask are faster when it is preceded by a prime that shares attributes critical to the correct response ([Ansorge, Heumann, & Scharlau, 2002](#); [Klotz & Neumann, 1999](#); [Taylor & McCloskey, 1990, 1996](#)).

But are these responses to the mask reflecting a direct subliminal influence on an ongoing action? Or is the influence on the initiation of an already-prepared action? In a recent study designed to document direct subliminal influences on the on-line control of action, [Schmidt \(2002\)](#) modified a metacontrast masking procedure so that his participants made short aiming movements in response to the colour of the mask (instead of the usual presses on keys in fixed locations). Red and green prime disks were first presented simultaneously in opposite quadrants of a screen, 32 mm away from a central fixation point. These prime disks were displayed for 10 ms and then masked by red and green annuli (rings) that appeared 10–60 ms after the onset of the primes. At each prime location, the annulus colour was either the same as the previous prime (an example of a *congruent trial*, in which the prime and mask indicated the same response was required) or opposite (an example of an *incongruent trial*, in which the mask indicated the alternative response to that initially specified by the prime was required). Participants were instructed to move their finger quickly and accurately from the central home position to the annulus with a pre-specified colour (e.g., red).

Despite the fact that the prime disks were masked so that their colour could only be correctly discriminated 55–65% of the time (chance = 50%), [Schmidt](#) reported that motor responses to the mask were strongly influenced by location of the red prime disk. Participants tended to begin their movements approximately 230 ms after prime onset, regardless of the prime-mask onset asynchrony. Most importantly, these movements initially began in the direction of the red prime disk and so were slower to complete on incongruent trials (when the red mask annulus appeared in another location) than on congruent trials (when the red mask annulus was in the same location). A kinematic analysis revealed that these movement trajectories were modified while the finger was in flight, with noticeable corrections on incongruent trials and a single fluid limb motion on congruent trials.

[Schmidt's \(2002\)](#) results clearly show that the colour of the subliminal prime disks influenced the trajectory of a limb movement. However, it is not clear that this influence was on the on-line control of action, as claimed. Instead, it is possible that only the initiation of the response (e.g., move to the red location) was influenced by the prime, with the decision to initiate the movement on the basis of the prime leading to more rapid success on congruent trials and less direct success on incongruent trials. If so, the effects of the prime were on movement initiation not on the control of ongoing action.

This leaves us with the question of whether subliminal shapes can influence the on-line control of action, specifically whether they can influence an action after a different action has already been initiated. To address this question, we modified [Schmidt's \(2002\)](#) procedure such that the critical prime-mask sequence was presented after the initiation of a goal-directed movement. The sequence of events is illustrated in [Fig. 1](#). Participants were given a fixed movement goal, to complete a rapid movement to a center target location. On 75% of trials,

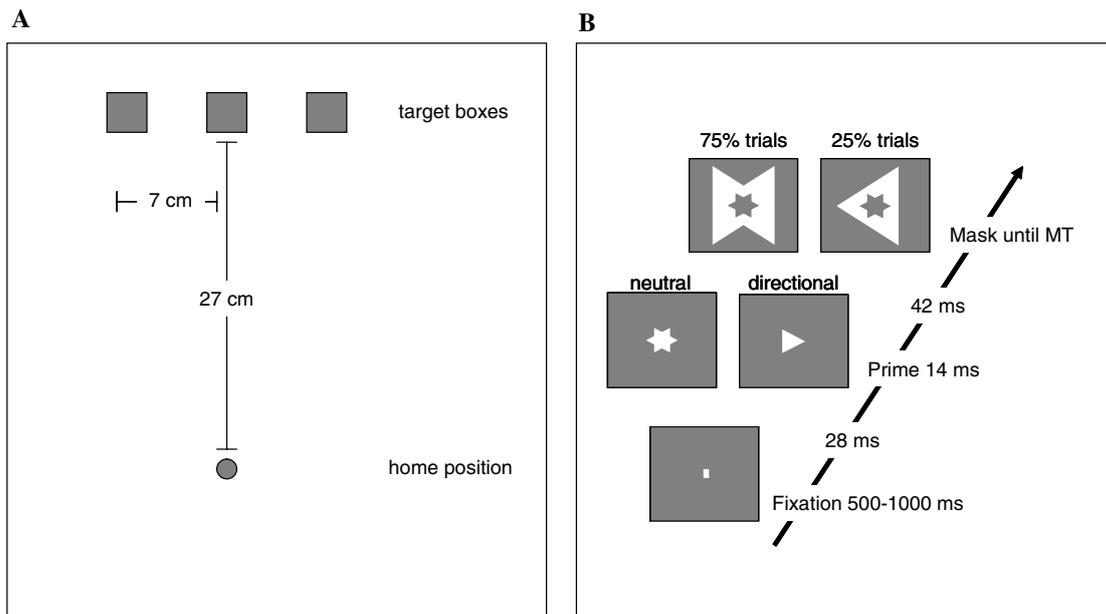


Fig. 1. (A) Overview of visual display in the pointing task. Participants were instructed to make a pointing movement from the home position to the center target box with a movement time goal of 300–500 ms. Directional arrows cued participants to modify their movements to the center target and land in either a left or right eccentric target. (B) Temporal sequence of a direct pointing trial (left) and a perturbed pointing trial (right). In the pointing task, 75% of the trials were cued responses to the central target (neutral prime + neutral mask). On the remaining 25% of trials, participants had to modify their final movement goal in the direction specified by the mask (left or right). The prime-mask sequence was displayed upon movement onset.

they simply performed the task of pointing to a target shape that appeared in the center of the display. However, on 25% of trials, a directional arrow prime-mask sequence was presented in the center location. This directional mask was the signal for participants to modify their pointing movement so that their finger landed in either the left or the right eccentric target location, according to the direction indicated by the mask.

We reasoned that if masked primes could influence the on-line control of a goal-directed movement we would observe deviations in movement trajectories that corresponded to the identity of the unseen primes shortly after the onset of those primes. Furthermore, there should be a difference in the trajectories observed for congruent and incongruent prime-mask pairs. On the other hand, if masked primes are only able to influence the initiation of an already-prepared action then deviations in the movement trajectories should only be seen in response to the direction indicated by the visible mask. Congruent versus incongruent prime-mask pairs should then not have any influence on movement trajectories.

## 2. Method

### 2.1. Participants

Eleven right-handed university students (7 female, 4 male, mean age =  $21.9 \pm 2.2$  years) with normal or corrected-to-normal visual acuity participated in this study. Participants were paid \$20 for their involvement. All participants gave informed consent, and the study was conducted in accordance with the ethical guidelines set by the University of British Columbia. Data from one participant were excluded for failure to follow task instructions.

### 2.2. Apparatus

Shapes were presented in white on a black background (Viewsonic 19" monitor, 70 Hz refresh), oriented 20 degrees from the horizontal. Participants viewed the display from a distance of approximately 60 cm, with their head movements restricted by a chin-rest. The participants were positioned such that their midline

was aligned with the center of the display and a home position (demarcated by a 12 mm circular marker) located centrally at the bottom of the display. In all tasks, stimuli were presented in the center of the display, located 27.0 cm directly above the home position. A DOS-based microcomputer was used to control stimulus presentation and data collection.

### 2.3. Stimuli

Prime shapes ( $4 \times 9$  mm) consisted of a left-pointing and right-pointing arrow, as well as a neutral shape formed from the superimposition of the two arrows. Masks consisted of larger ( $23 \times 28$  mm) versions of the same shapes as the primes, with a central cutout (see Fig. 1). The outer contour of the prime stimuli fit exactly within the inner contour of the central cutout of the masks. In all trials, primes were presented for 14 ms and the prime-mask stimulus-onset asynchrony (SOA) was set at 56 ms. The SOA duration was selected based on pilot experiments demonstrating that it produced the strongest metacontrast masking. Masks were presented at the same central position as the primes until the pointing response was complete (approximately 400 ms).

### 2.4. Movement analysis

Participants performed the pointing task with a stylus in their right hand. An infrared-emitting diode was placed at the tip of the stylus and 3D position was monitored using an OPTOTRAK (Northern Digital, Waterloo, Ontario) motion analysis system (spatial resolution 0.01 mm). The tip of the stylus was equipped with a microswitch that provided an analog signal indicating whether or not the stylus was in contact with the surface of the display. The 3D position of the stylus and the status of the microswitch were sampled at 500 Hz. Raw data from the OPTOTRAK were converted into 3D coordinates and digitally filtered using a second order dual-pass Butterworth filter with a low-pass cutoff frequency of 10 Hz. The start and end of the movement was determined by the status of the stylus microswitch.

### 2.5. Procedure

Participants completed three tasks in a single experimental session. First, they performed the *Mask Response Time* task. Participants rested their left and right index fingers on the left “z” key and right “/” key of a standard keyboard, respectively. The keyboard was centered on the home position. Participants were instructed to direct their attention to a fixation point at the center of the display monitor (500–1000 ms) and respond as quickly and as accurately as possible to the direction of the mask arrow (left or right) with the corresponding key press. Mask arrows were preceded by a left-pointing, right-pointing, or neutral prime arrow (14 ms). Prime-mask SOA was 56 ms. Participants completed a single block of 120 trials.

Participants then performed the *Mask Pointing* task, which involved making pointing movements from a home position to a center square target ( $3.3 \text{ cm}^2$ ) 27.0 cm away. The center target was flanked on each side by square targets such that the distance between the middle of the center target and the left or the right target was 7.0 cm. Participants could begin their movement to the center target anytime following the appearance of the target boxes (with no reaction time constraints). On 75% of the trials (direct pointing), movement of the stylus initiated the appearance of the neutral prime shape (14 ms) followed by a neutral mask shape (SOA = 56 ms) in the center target box. Participants were instructed that when this neutral mask shape appeared they were to continue pointing to the center target with a movement time goal of 300–500 ms. On the remaining 25% of trials (perturbed pointing), the prime was one of three shapes (left arrow, right arrow, neutral shape) and the mask in the center box was either a left or a right pointing arrow. Participants were instructed that the mask arrow was a signal to modify their pointing movement to the center box and to complete their point by landing in the box indicated by the mask arrow.

Participants began with 20 practice trials of direct pointing. They then completed 2 blocks of 240 test trials in which the 75% of direct pointing trials were randomly interspersed with the 25% of perturbed pointing trials. Movement time was measured from stylus lift-off to stylus contact with one of the target boxes. Participants were given a movement time goal of 300–500 ms and movement time feedback was provided following all direct pointing trials.

The final task performed by all participants was *Prime Identification*. Participants were told that one of three prime shapes would be presented randomly on each trial and their task was to identify them by making a 3-alternative forced choice. They were also told that only accuracy was being measured and that response speed was no longer important. The display sequence was identical to the mask pointing task. Participants viewed the prime-mask sequence with their right index finger resting on the space bar. A tone sounded 400 ms following the mask, indicating that the participant could respond by pressing the left key (b), the center key (n), or the right key (m) with their right index finger to indicate a left-pointing, neutral or right-pointing prime arrow, respectively. Each participant completed 120 trials.

### 3. Results

#### 3.1. Prime identification: primes were barely visible to participants

At the beginning of the prime identification task, all participants were surprised to learn that mask arrows had been preceded by prime arrows. These subjective reports were confirmed by their performance in the prime discrimination task. Chance performance in this task was 33% (given the three equally likely alternatives). Mean accuracy collapsed across all prime-mask sequence combinations was  $39.67\% \pm 17.16$  (SD), which differed significantly from the chance level of 33.3% at the  $p < .05$  level, but not at the  $p < .01$  level,  $t(1,9) = 2.7$ . This is less than the level of visibility reported by Schmidt (2002), where accuracy was at 60% and chance was 50%.

We also noted that prime accuracy differed significantly, depending on the relation between prime and mask. Mean accuracy on incongruent prime-mask trials did not differ significantly from the chance level of 33% ( $34.5\%$ ,  $t(9) < 1$ ), but mean accuracy on congruent prime-mask trials was significantly greater ( $52.8\%$ ,  $t(9) = 4.60$ ,  $p = .001$ ). A data pattern like this has been attributed to a biasing influence of the visible mask on reports of the prime rather than a true measure of prime visibility (Vorberg, Mattleer, Heinecke, Schmidt, & Schwarzbach, 2003), and as such, prime accuracy on incongruent trials may be underestimated. However, in the present data we have an additional condition, the neutral mask, which allows us to measure prime accuracy without any possibility of response bias. Accuracy on neutral prime trials did not differ significantly from chance ( $31.8\%$ ,  $t(9) < 1$ ), suggesting that by the strictest measure available in the present experiment, prime visibility could not play any explanatory role in the priming effects we obtained.

#### 3.2. Mask response time: invisible primes influence response selection

Participants were very accurate in the mask response time task ( $>97\%$  correct overall) and mean correct response times (RT) with respect to the neutral prime trials are shown in Fig. 2. In addition to the difference scores displayed in Fig. 2, the RTs for all prime-mask trial combinations are provided in Table 1. The influence of the prime arrows on these responses can be seen in the large statistical interaction between prime and mask shapes,  $F(2, 18) = 128.761$ ,  $p < .001$ . Post hoc mean comparisons (Tukey HSD) revealed that RT was smaller when masks were preceded by congruent primes than by either incongruent ( $p < .05$ ) or neutral primes ( $p < .05$ ). Furthermore, mean RT was larger for incongruent displays than for neutral displays ( $p < .05$ ). This replicates the previously reported finding that invisible primes influence choice response times to the identities of similar looking masks (Ansorge et al., 2002; Klotz & Neumann, 1999; Taylor & McCloskey, 1990, 1996).

#### 3.3. Mask pointing: invisible primes influence the on-line control of action

Participants were able to complete the movement to the center target on direct pointing trials within the required movement time ( $\bar{x} = 392$  ms  $\pm 40.5$  SD). When the directional masks appeared on perturbed trials, participants were able to successfully modify their movements and land in the appropriate eccentric target on the majority of trials ( $\bar{x} = 86.1\% \pm 18.1$  SD). On the 14% of perturbed trials on which participants failed to modify their pointing correctly, their fingers always landed in the center target within the movement time goal. However, this error occurred less frequently when a directional prime preceded the directional mask (congruent =  $8\% \pm 12.4$  SD; incongruent =  $7\% \pm 7.3$  SD), than when a neutral prime preceded the directional

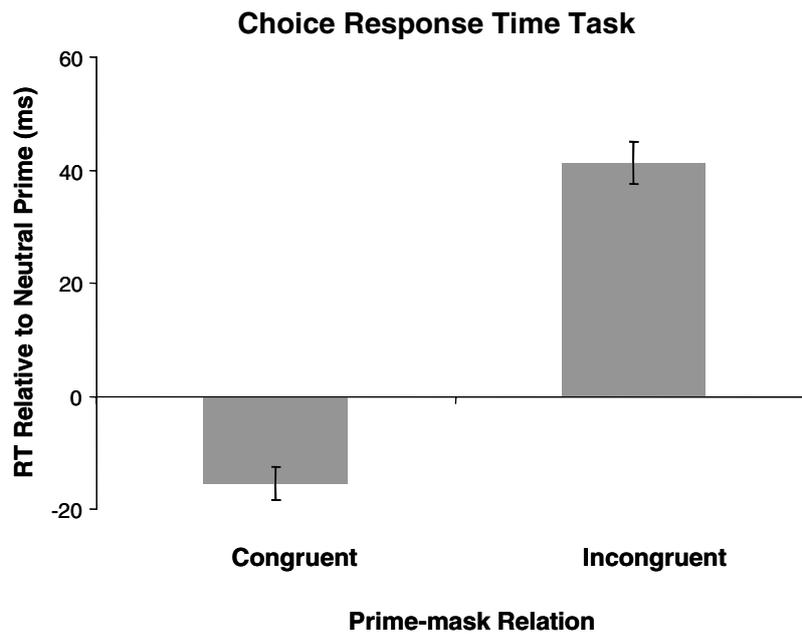


Fig. 2. Effect of prime-mask congruency on choice response times (RT) to the mask stimulus. Results are shown for congruent and incongruent prime-mask combinations with respect to mean performance on trials in which a neutral prime was displayed. Note: a negative score indicates responses were initiated faster than when a neutral prime was displayed, whereas a positive score indicates performance was slower. Error bars denote standard errors. A breakdown of the choice RTs are provided in Table 1.

Table 1

Mean (SE) response times (ms), pointing movement times (ms), and times of final trajectory modifications in the goal-directed movement

	Congruent prime-mask	Incongruent prime-mask	Neutral prime-directional mask
Response time (ms)	333.2 (9.5)	389.9 (7.1)	348.6 (9.2)
Pointing movement time (ms)	515.0 (12.1)	571.7 (10.9)	581.8 (11.9)
Final trajectory modification (ms)	277.3 (4.4)	333.0 (4.6)	321.6 (4.1)

mask ( $\bar{x} = 26\% \pm 23.9$  SD,  $F(2, 18) = 9.738$ ,  $p = .001$ ). This is therefore initial evidence that the prime shape (in this case the neutral prime) influenced the ultimate target of the pointing action.

Movement time (MT) on corrected perturbed trials, with respect to perturbed trials in which the neutral prime was displayed, is shown in Fig. 3 and MT for all prime-mask combinations provided in Table 1. In addition to the error results, the MT results indicate that the prime-mask relationship influenced the pointing response,  $F(2, 18) = 39.52$ , ( $p < .001$ ) (see Fig. 3). Post hoc tests (Tukey HSD,  $p < .05$ ) indicated that participants were faster to complete movements to an eccentric target when the directional mask was preceded by a congruent than an incongruent prime. The difference in movement time between incongruent and neutral primes was not significant. These results indicate that the primes were having an influence on the overall time required to complete a successful pointing modification.

But at what point in the ongoing pointing action did the primes begin to have an influence? To examine this question, we compared pointing trajectories for the perturbed trials in which participants moved to the correct eccentric target to an average spatial trajectory computed for the direct pointing trials. The average spatial trajectory in the 2D plane was calculated for each participant from all direct pointing trials in the two testing blocks. The points in this trajectory were obtained by deriving the mean lateral spatial position in the  $x$ - $y$  plane for every 2 mm of forward movement progression. If a trajectory did not have a position value at the exact spatial location required, one was obtained by linear interpolation from the closest data points within a maximum distance of 1 mm. In addition, the standard deviation of the mean position in the  $x$ -direction was also calculated. The resulting mean spatial trajectory, together with its 2 standard deviation bandwidth, then became the standard against which pointing on perturbed trials were assessed (see Cressman, Franks, Enns, & Chua, 2006).

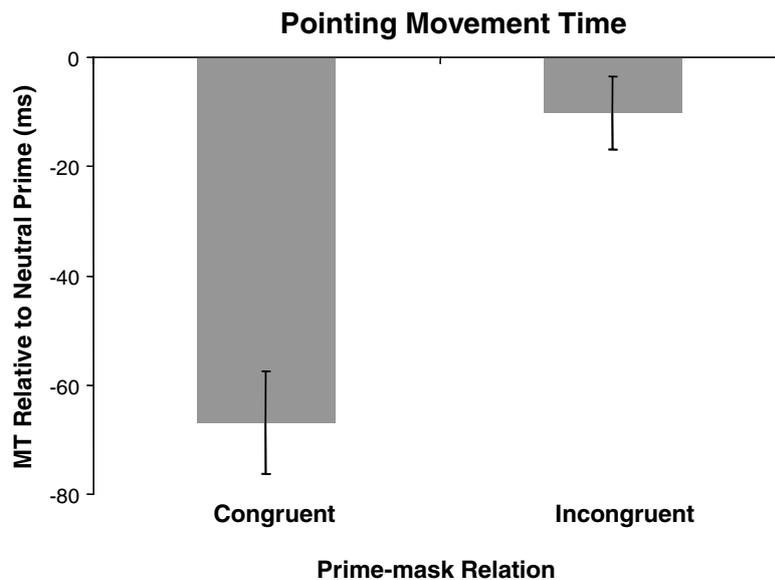


Fig. 3. Movement times (MT) to eccentric targets with respect to mean performance on trials in which a neutral prime preceded the directional mask. A negative score indicates a faster movement was completed to the eccentric target than when a neutral prime was displayed and a positive score indicates a slower movement. Error bars denote standard errors. A breakdown of MTs are provided in Table 1.

Fig. 4 illustrates a mean spatial trajectory, computed from the direct pointing trials, and individual perturbed trials in which a participant responded to a left-pointing arrow mask and landed in the left target. From the mean path displayed (open circles) it appears that the trajectories on direct trials move in a fairly straight line toward the center target box. In contrast, the trajectories on perturbed trials differed substantially from the direct pointing trials and from each other depending on the shape of the prime displayed. In the perturbed pointing trials (solid lines), trajectories initially deviated in the direction of the prime, regardless of the mask displayed. Thus there was no inhibition, as the primes activated a response directly. Pointing modifications to the left goal target were made earlier for congruent primes than neutral primes, and pointing modifications were initially made in the wrong direction for incongruent primes.

To examine these differences in movement perturbations, a conservative estimate of the time at which the movement began to deviate toward the target specified by the mask (i.e., left target) was calculated. This estimate was defined as the point in time at which displacement in the horizontal axis of the movement reached a maximal value and showed a reversal toward the appropriate eccentric target. These mean estimates, with respect to perturbed trials in which the neutral prime is displayed, are shown in Fig. 5 and mean values provided for all prime-mask congruencies provided in Table 1. The time at which the movement began to deviate toward the target specified by the mask is dependent on prime-mask congruency ( $F(2, 18) = 86.188$ ,  $p < .0001$ ). Tukey HSD analyses revealed that modifications to congruent primes occurred earlier than to incongruent or neutral primes ( $p < .05$ ), with no difference between incongruent and neutral primes.

An examination of the lateral displacement made in completing the pointing movement to the eccentric target from the point in the trajectory at which the pointing modification had begun showed that participants made shorter movements when the prime was congruent ( $\bar{x} = 70.0 \text{ mm} \pm 15.3 \text{ SD}$ ) or neutral ( $\bar{x} = 70.7 \text{ mm} \pm 13.0 \text{ SD}$ ) than when it was incongruent ( $\bar{x} = 79.2 \text{ mm} \pm 14.9 \text{ SD}$ ),  $F(2, 18) = 19.886$ ,  $p < .001$ . Yet, at the same time, the total movement time in the incongruent and neutral conditions were not different from one another. To examine how this came about, we explored the possibility that participants completed the late portion of the trajectory more quickly when the primes were incongruent than when they were neutral. An analysis of the peak lateral velocity during this final trajectory segment revealed that this was indeed the case,  $F(2, 18) = 13.771$ ,  $p = .001$ . On average, participants reached greater peak velocities during this final movement segment when the prime and mask were incongruent ( $\bar{x} = 533.3 \text{ mm/s} \pm 64.8 \text{ SD}$ ) than when they were congruent ( $\bar{x} = 475.7 \text{ mm/s} \pm 38.9 \text{ SD}$ ) or neutral ( $\bar{x} = 478.9 \text{ mm/s} \pm 31.8 \text{ SD}$ ).

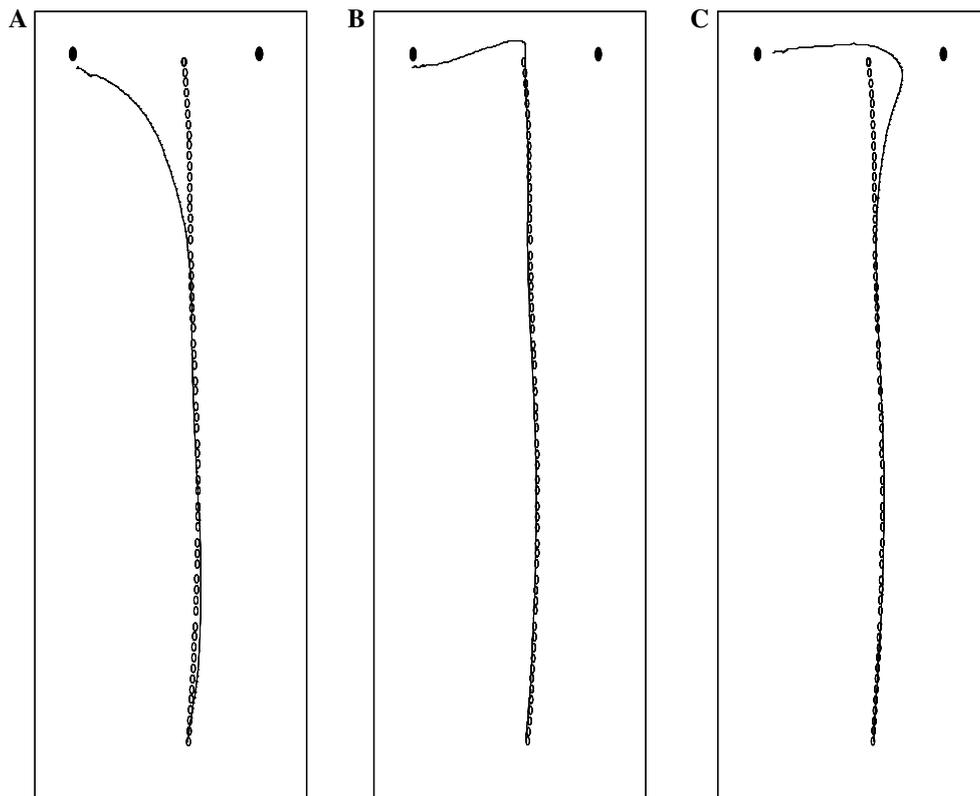


Fig. 4. Examples of mean direct spatial trajectories (open circles) and individual perturbed spatial trajectories (solid line) under each of the three conditions in which a left directional mask was displayed [(A) congruent prime, (B) neutral prime or (C) incongruent prime]. The center of the eccentric target boxes are indicated by annuli (the center target box is not visible). Note the early trajectory deviation to the left eccentric target in the congruent trial and the initial incorrect trajectory deviation in the incongruent trial.

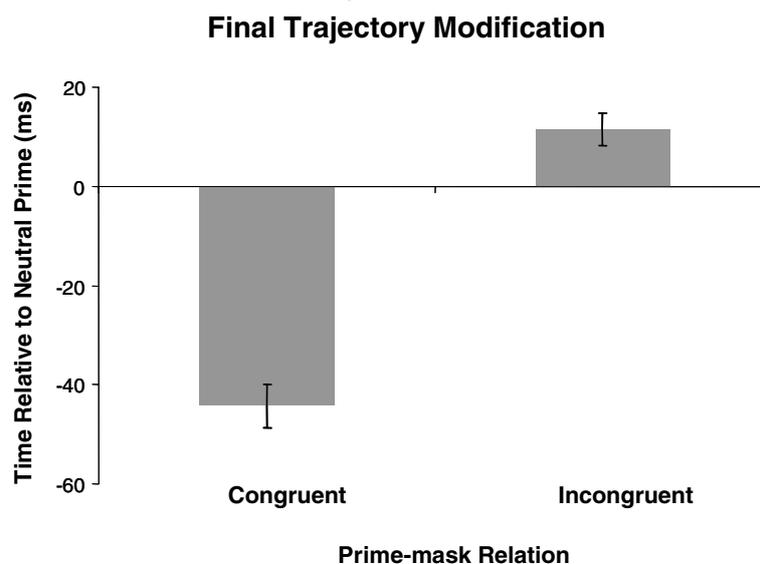


Fig. 5. Latencies of final trajectory reversal, at which point participants began to move to the eccentric target cued by the directional mask, with respect to mean performance on trials in which a neutral prime preceded the directional mask. A negative score indicates a movement was initiated earlier to the eccentric target than when a neutral prime was displayed, whereas a positive score indicates the modification in trajectory occurred at a later point in time. Error bars denote standard errors. A breakdown of the results are provided in Table 1.

#### 4. Discussion

The goal of the present experiment was to determine if subliminal shapes are capable of influencing the on-line control of action. To address this question, we used a metacontrast masking procedure in which the critical prime-mask sequence was presented after the initiation of an already-prepared target-directed movement. As a comparison with previous findings, we also required participants to complete a choice response time task in which the prime-mask sequence was presented prior to the selection and initiation of discrete key press responses. Finally, we required participants to perform a perceptual discrimination task, in which they attempted to identify the masked primes. These procedures allowed us to demonstrate three important findings.

First, we established that the prime shapes in our procedure remained inaccessible to participants' conscious awareness. This replicates numerous previous studies of masked priming. Second, we demonstrated that invisible primes influence the latency of motor responses in the choice response time task, as previous studies have also shown (Ansorge et al., 2002; Breitmeyer, Ro, & Singhal, 2004; Neumann & Klotz, 1994; Taylor & McCloskey, 1990, 1996). Third, and most important for the goal of our study, we showed that these same subliminal shapes not only can influence the speed with which a goal-directed action is initiated, as in previous studies (Schmidt, 2002), but they can influence the control of ongoing action.

The novel contribution of this study is that it showed the influence of invisible primes for ongoing goal-directed actions, rather than merely in the initiation of these actions. The main evidence for this was that initial deviations in movement trajectories from the center target were always in the direction cued by the prime, regardless of the direction of the subsequent mask. Participants did not wait for information from the mask before they began to modify their movements. Thus congruent primes gave the pointing modification a head start in the correct direction, with modifications occurring within 277 ms of movement onset. In contrast, incongruent primes resulted in initial trajectory deviations toward the wrong target. Consequently, additional movement time was required for participants to correct the movement. Pointing trajectories were not directed to the correct target until participants had reacted to the mask, approximately 330 ms into the movement. When a neutral prime preceded the directional mask, participants adjusted their trajectories in response to the mask at latencies similar to those observed in incongruent prime trials, as in both incongruent and neutral perturbed trials the movement goal was not specified until the mask was displayed. The difference in movement correction latencies between congruent (277 ms) versus incongruent and neutral (330 ms) prime-mask trials was approximately equal to the prime-mask SOA (56 ms). This suggests that new pointing-relevant visual information is incorporated into control of the pointing action as soon as it becomes available.

Taken together, the difference in the latency of trajectory modifications to the correct eccentric target in congruent trials compared to incongruent and neutral prime trials, as well as the short latency of these pointing modifications, suggest that participants processed and responded to the primes and masks in feed-forward manner. Movement trajectories to the center target were modified on-line, first in response to the invisible prime and then if necessary, in response to the visible mask. Thus, we can be confident in this study that the prime did not influence the initiation of an already-prepared movement. Rather, the primes influenced the on-line control of a goal-directed action. Furthermore, the prime's influence appears to have been automatic, as defined by previous research examining the ability to make rapid, on-line adjustments in limb movements in response to unexpected changes in the location, shape, and orientation of a target object (e.g., Bard et al., 1999; Brenner & Smeets, 2003; Cressman et al., 2006; Desmurget & Prablanc, 1997; Desmurget et al., 1999; Paulignan, MacKenzie, Marteniuk, & Jeannerod, 1991; Pisella et al., 2000; Prablanc, Pélisson, & Goodale, 1986).

The automatic influence of invisible primes on an ongoing visually guided action can best be characterized within Neumann's theory of *direct parameter specification* (DPS) (Neumann, 1990; Neumann & Klotz, 1994). According to DPS, there is a direct link between sensory information and the response parameters concerning when and how to respond, which does not require mediation by conscious processes. For example, as a consequence of instruction, action planning takes place and a conditional readiness is established. Visual information can be fed into the motor system without reaching conscious awareness. A response is activated if the sensory related activity contains relevant features critical to a given response.

DPS can readily account for most features of the priming effects we observed in both our response time and pointing tasks. Specifically, when prime and mask were congruent, responses were fastest in the response time

task and pointing trajectories deviated earliest to the correct target in the pointing task. However, there is one difference in the pattern of participants' responses between the two tasks that DPS does not readily explain. In the response time task, participants' first recorded response was almost always consistent with the identity of the mask and not of the prime (accuracy was above 97% in that task). In contrast, when participants were pointing based on the masks, the first recorded responses (trajectory deviations) were observed in the direction of the prime, whether or not the prime was congruent with the subsequent mask. Thus, participants in the choice response time situation appeared to have waited until they identified the mask before committing to an overt response. They did not make an observable response to the identity of the prime in the response time task as they did in the pointing task (cf. Schmidt, 2002). This is likely why the neutral prime RTs are more similar to the congruent prime RTs in the choice response task and why the neutral MTs are more similar to the incongruent MTs in the pointing task; actions in the choice task must be withheld until the final mask information is available whereas in the pointing task there is no obvious penalty for a premature deviation in the direction of the prime.

This difference in response patterns for the two tasks suggests that there is flexibility in the way subliminal information is used for the control of action. At this point we can only speculate on how this flexibility in visuo-motor processing is accomplished. One possibility in keeping with DPS theory (Neumann, 1990; Neumann & Klotz, 1994) is that of a fluctuating motor activation threshold. The level of this threshold could be strategically set at different levels, depending on task constraints. In a pointing task such as the one studied here, and in Schmidt's (2002) response time task, participants are able to correct initial response errors and still complete the task successfully, regardless of initial deviations from the immediate action goal. For this reason, a lower activation threshold could be set, allowing prime-related activity to influence responses with little to no monitoring. In contrast, in the choice response time task, the penalty of pressing the incorrect key would prompt the setting of the activation threshold at a higher level. We offer this account of the differences between the two tasks as a working hypothesis. Future experiments will be needed to fully explore the flexibility in prime activated responses. For now, the results show conclusively that masked shapes can influence both response initiation and the on-line control of goal-directed actions in the absence of conscious awareness.

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