

# Influence of Near Threshold Visual Distractors on Perceptual Detection and Reaching Movements

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**Deplancke A, Madelain L, Chauvin A, Cardoso-Leite P, Gorea A, Coello Y.** Influence of near threshold visual distractors on perceptual detection and reaching movements. *J Neurophysiol* 104: 2249–2256, 2010. First published August 17, 2010; doi:10.1152/jn.01123.2009. Providing evidence against a dissociation between conscious vision for perception and unconscious vision for action, recent studies have suggested that perceptual and motor decisions are based on a unique signal but distinct decisional thresholds. The aim of the present study was to provide a direct test of this assumption in a perceptual-motor dual task involving arm movements. In 300 trials, 10 participants performed speeded pointing movements toward a highly visible target located at 10° from the fixation point and  $\pm 45^\circ$  from the body midline. The target was preceded by one or two close to threshold distractor(s) (80 ms stimulus onset asynchrony) presented  $\pm 30^\circ$  according to the target location. After each pointing movement, participants judged whether the distractor was present or not on either side of the target. Results showed a robust reaction time facilitation effect and a deviation toward the distractor when the distractor was both present and consciously perceived (Hit). A small reaction time facilitation was also observed when two distractors were physically present but undetected (double-miss)—this facilitation being highly correlated with the physical contrast of the distractors. These results are compatible with the theory proposing that perceptual and motor decisions are based on a common signal but emerge from a contrast dependent fixed threshold for motor responses and a variable context dependent criterion for perceptual responses. This paper thus extends to arm movement control previous findings related to oculomotor control.

## INTRODUCTION

In the last two decades, considerable effort has been devoted to understand the relation between perception and action both at the behavioral and neurobiological level. The dominant model originally proposed by Ungerleider and Mishkin (1982) and re-interpreted by Goodale and Milner (1992) for the visual system describes an anatomical and functional dissociation between two pathways projecting from the visual cortex (V1), respectively, to the inferotemporal cortex (the ventral stream) and to the posterior parietal cortex (the dorsal stream). According to Goodale and Milner, the role of each stream must be understood not only from the point of view of the visual inputs but also in terms of the outputs generated within each stream. Accordingly, the visual inputs processed through the dorsal stream are thought to mediate the visual control of action,

while visual inputs processed through the ventral stream are thought to be important for conscious perception, object recognition and scene parsing (Goodale 2008; Goodale and Milner 1992; Goodale et al. 2005; Milner and Goodale 1995, 2008).

One of the main arguments in favor of a separation between perception and action was the observation of different effects of the same visual information on motor responses and conscious perception. Evidence supporting this dissociation came largely from visual illusions studies (Aglioti et al. 1995; Bridgeman et al. 1981; Coello et al. 2007; Gentilucci et al. 1996; Kroliczak et al. 2006; Zivotofsky 2004), neuropsychological cases (for reviews, see Goodale 2008; Goodale et al. 2005; Milner and Goodale 1995, 2008), and subthreshold priming experiments (Amundson and Bernstein 1973; Binsted et al. 2007; Cressman et al. 2007; Ogmen et al. 2003; Taylor and McCloskey 1990), all suggesting the capacity of the motor system to deal with a visual stimulus independently from the perceptual state evoked by the same visual stimulation (Jáskowski et al. 2003; Pisella et al. 2000). Among these studies, masking paradigms have been particularly used to argue in favor of a dissociation between conscious vision for perception and unconscious vision for action. When the visibility of priming information was prevented or reduced by the presence of a mask (backward masking) (for a review, Breitmeyer and Ogmen 2000), motor responses were nonetheless affected by the prime even when the latter was not perceived consciously (Amundson and Bernstein 1973; Cressman et al. 2007; Ogmen et al. 2003; Taylor and McCloskey 1990). Interestingly, it has also been shown that early visual responses in the prefrontal cortex are present even when using backward masking (Thompson and Schall 1999). In agreement with this, Binsted et al. (2007) showed that when healthy participants were asked to perform manual pointing movements toward targets of different sizes, the dynamics of their movements followed Fitt's Law, i.e., they varied with the physical size of the target (Fitts 1954) even when the latter couldn't be consciously reported.

However, both the methodology and conclusions of such studies have been repeatedly challenged (Holender 1986; Holender and Duscherer 2004; Reingold and Merikle 1988, 1990; Waszak and Gorea 2004; Waszak et al. 2007) and debated (Goodale 2008), emphasizing the impact of the experimental conditions in which (in)dependency between perceptual and motor responses were observed (e.g., characteristics of the stimuli, responses and tasks) (see Cardoso-Leite and Gorea 2010 for a review). As a consequence, an alternative theory has

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been proposed, positing that perceptual and motor decisions are based on a common incoming signal but emerge from a contrast dependent, fixed threshold for motor responses and a variable context dependant criterion for perceptual responses (Cardoso-Leite and Gorea 2010; Waszak and Gorea 2004; Waszak et al. 2007). This proposal followed a series of experiments using signal detection theory (SDT) (Green and Swets 1966) to analyze, on a trial-by-trial basis, both the perceptual state evoked by close to threshold visual stimulations and the effect of these stimulations on motor performance. Such studies have revealed a strong relation between perceptual and motor responses with low contrast visual stimuli when testing manual reaction times and perceptual detection (Waszak and Gorea 2004; Waszak et al. 2007), manual reaction times and perceptual latencies (Cardoso-Leite et al. 2007, 2009), and saccade curvature and confidence judgments (Cardoso-Leite and Gorea 2009).

Concerning the latter point, irrelevant (supra threshold) distractors in visual target reaching tasks have been shown to entail deviations of eye (for a review, see Van Der Stigchel et al. 2006) and hand trajectories (Lee 1999; Sailer et al. 2002a,b; Song and Nakayama 2006, 2008; Tipper et al. 1997). The dominant interpretation of these deviations is inspired by Tipper's population coding theory (Tipper et al. 1997, 2000, 2001), which predicts that both visual target and distractor trigger the activation/excitation of a specific region of the motor map in the superior colliculus and that the final vector for the movement is determined by averaging of these signals (Lünenburger et al. 2001; McPeck and Keller 2004; Robinson 1972; Wurtz et al. 1980). The direction of the deviation associated with the activation is constrained by the temporal parameters of the movement: a deviation toward the distractor is preferentially observed for short latency responses (expression of excitatory mechanisms only), whereas for longer latency responses (i.e., generally >200 ms) (McSorley et al. 2006), a reactive inhibition of the activity causes a deviation away from the distractor (Bompas and Sumner 2009; McSorley et al. 2006; Tipper et al. 2001). Exploring saccadic deviations induced by the presence of near threshold distractors, Cardoso-Leite and Gorea (2009) observed that deviations away from the distractor depended on the perceptual state evoked by this distractor, i.e., trajectories deviated away from the distractor only when the latter was consciously perceived even when not physically presented (i.e., for perceptual hits and false alarms). This result suggests that the interaction between perceptual and motor decisions could occur during the initial stages of visual processing; supporting the view that reactive inhibition mechanism operates on a perceptual state dependent excitation process. However, Cardoso-Leite and Gorea (2009) observed only deviations *away* from the distractor suggesting a perceptual state dependent *reactive inhibition process*. Their results suggested nonetheless the possibility of a perceptual state dependent *early excitatory process*, and the aim of the present study was to directly test this assumption. Furthermore, as using various modes of motor responses is essential to determine to what extent previous results can be generalized, we addressed the effect of near threshold stimuli on arm reaching movements.

In the present study, participants had to perform a dual task: a fast pointing movement toward a suprathreshold target and a detection task bearing on a close to threshold distractor pre-

sented on the right and/or the left of the visual target. Motor performances were then classified according to participants' perceptual state as defined by the conjunction of their perceptual response and the presence/absence of the distractor, namely hits (distractor present and detected), misses (distractor present but not detected), false alarms (FAs, distractor absent but reported), and correct rejections (CRs, baseline: distractor absent and not reported).

To specifically focus on the early excitatory process evoked by the distractor, we designed an experiment where only this first excitatory process was assumed to be active and to entail deviations *toward* the distractor ("global effect") (Findlay 1982). We thus used short reaction time arm movements (McSorley et al. 2006) and low predictability of target and distractors locations (Walker et al. 2006). We also maximized the competition between the target and distractor evoked signals by using a stimulus (SOA) onset asynchrony of 80 ms between the distractor(s) and target presentation (Bompas and Sumner 2009). If the early excitatory process depends on participants' perceptual state, hand trajectory should deviate *toward* the distractor in both perceptual hit and FA trials and should remain unaffected by it in miss trials (compared with CR trials). By contrast, an early excitatory process that is independent of perceptual detection should produce equivalent arm-pointing deviations toward the displayed distractor in hit and miss trials without deviation in FA trials.

## METHODS

### Participants

Ten voluntary naïve participants were included in this experiment (5 males and 5 females, mean age: 26 yr). They all had normal or corrected-to-normal visual acuity and were all right-handed.

### Apparatus

The experimental apparatus is depicted in Fig. 1. It is a rectangular box (60 cm high, 90 cm wide, and 75 cm deep) with the inside divided horizontally by a mirror. Stimuli were displayed on a 21-in CRT (1,024 × 768 pixels, 100 Hz, mean background luminance on the mirror: 3.5 cd/m<sup>2</sup>) monitor placed upside down on the top surface of the apparatus, allowing participants to perceive the projection of the

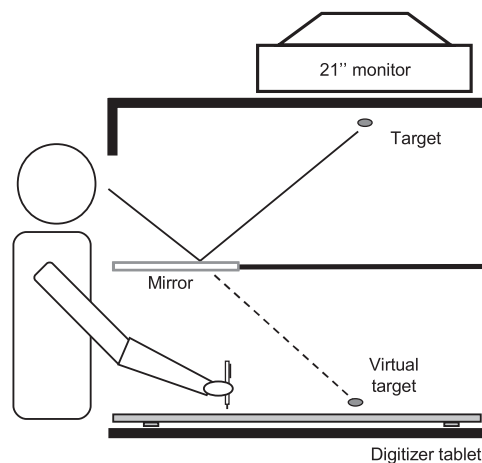


FIG. 1. Line drawing of the experimental apparatus. The monitor's image was projected on the horizontal workspace through a mirror dividing the box horizontally. The hand remained invisible during the whole experiment.

monitor's image on their horizontal workspace (see Fig. 1). The workspace was composed of a digitizer tablet (Wacom Intuos 3 PTZ-1231W, A3 size, spatial resolution: 0.02 mm, sampling rate: 200 Hz), which registered the  $x,y$  coordinates of an electromagnetic stylus (Grip Pen Intuos 3 ZP-501E) used by the participant to perform the pointing movements with the right hand (an occluder prevented vision of the hand). The head of the participant rested on a chin and forehead support tilted toward the mirror plane with a  $30^\circ$  angle. Perceptual responses were recorded by pressing the buttons of a mouse held in the left hand. The experimental room was maintained in darkness during the whole experiment. Stimulus display and response recording were controlled under Matlab 7.6.0. using the Psychophysics Toolbox (ptb -3) (Brainard 1997; Pelli 1997).

### Stimuli

The spatial and temporal layouts of the stimulations are illustrated in Fig. 2. The fixation point was a  $0.2^\circ$  diam dot with a 100% luminance contrast with respect to the background (see Fig. 2A). At the beginning of each trial, the fixation dot was displayed at the location of the stylus' physical starting zone materialized by a semi circular notch (2 mm diam) in a piece of wood fastened on the workspace. The pointing target stimulus was a Gaussian luminance blob (100% luminance contrast) with a SD of  $0.3^\circ$ . It was displayed at an eccentricity of  $10^\circ$  (8.5 cm) from the fixation point  $45^\circ$  left or right of the body midline (see Fig. 2B). The distractor was a Gaussian luminance blob with a SD of  $0.3^\circ$  and a luminance contrast adjusted so as to obtain a  $d'$  close to 1 (see preliminary experiment 2). It was

displayed at a distance of  $10^\circ$  from the fixation point and at an angle of  $30^\circ$  to the left and/or the right of the target.

### Procedure

Prior to the main experiment, participants performed two preliminary experiments to be familiarized with the speeded pointing responses and to determine their specific near-threshold distractors' contrast. In all experiments, participants placed the stylus on the physical starting zone where the fixation dot was visually presented and clicked on the stylus button when ready to start a trial. Following this click, the fixation dot was surrounded by 18 lines (length:  $0.3^\circ$ , thickness: 0.05) pointing toward the center of the dot. 250 ms later, the fixation dot contrast decreased to 50%, indicating the start of the trial. After a delay comprised between 700 and 1,300 ms, the target was displayed and remained visible until the end of the trial (Fig. 2A). When present, the near threshold distractor appeared systematically 80 ms before target onset.

**PRELIMINARY EXPERIMENT 1: SPEEDED MOTOR RESPONSE TRAINING.** This experiment was designed to encourage participants to produce fast motor responses and to establish a baseline distribution of reaction times (RTs). Participants had to perform 100 fast and accurate pointing movements toward the target, which could appear randomly either left or right of the fixation dot (no distractor trials, Fig. 2B). Invalid trials, i.e., trials with  $RT < 150$  ms or  $> 500$  ms, were signaled by a message displayed on the screen (e.g., "anticipation" or "late") and were repeated at the end of the sequence. The 95th percentile of the RT distribution of valid trials was taken as the maximum RT allowed during both the second preliminary and the main experiments.

**PRELIMINARY EXPERIMENT 2: NEAR THRESHOLD DISTRACTOR CONTRAST ASSESSMENT.** The goal of this experiment was to determine for each participant the distractor luminance contrast yielding a  $d'$  of  $\sim 1$  (i.e.,  $\sim 76\%$  correct responses in a two-alternative force-choice (2AFC) task).<sup>1</sup> Participants performed 300 pointing movements toward the target which appeared randomly either on the left or the right of the fixation point. In 100 (randomly chosen) trials, no distractor was presented (no distractor trials), whereas in the remaining 200 trials, one distractor was displayed (single-distractor trials)  $30^\circ$  either on the left or the right of the visual target. The distractor appeared for 10 ms, 80 ms prior to target onset (Fig. 2). Knowing that the use of a negative SOA is necessary to maximize the competition between low visibility distractors and high contrast targets (Bompas and Sumner 2009), this  $-80$  ms SOA was chosen as it yielded the largest trajectory deviation as revealed in a pilot experiment with 100% contrast distractors presented for 10 ms at 0,  $-40$ , or  $-80$  ms SOAs (data not reported).

The contrast of the distractor was randomly chosen within the range of 25–35% (10 different contrasts). The participants' perceptual task was to report the distractor's location (2AFC detection task) at the end of each trial. Participants' perceptual judgments in the no distractor trials were not considered for  $d'$  computation in this preliminary experiment.

**MAIN EXPERIMENT.** The aim of this experiment was to test the effect of the near-threshold distractor(s) on manual reaching movements as a function of the subjective detection/non-detection of the distractor(s) depending on whether or not it/they was/were presented. Participants performed 300 pointing trials in the double task paradigm illustrated

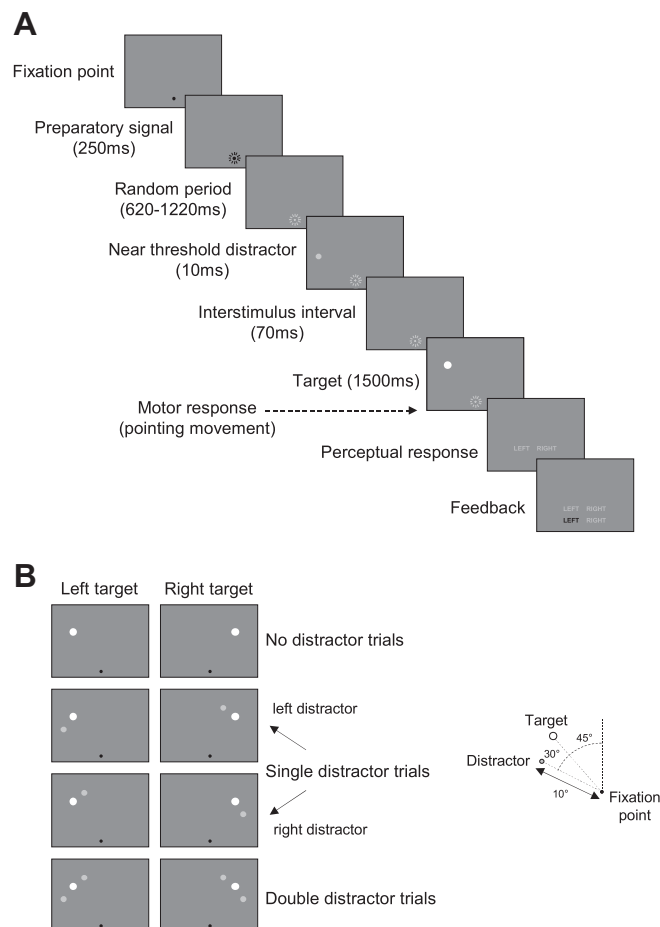


FIG. 2. A: temporal sequence of stimuli presentation. B: target and distractor(s) location for each trial and location of the target and the distractor(s) relative to the fixation point.

<sup>1</sup> Signal detection theory (Green and Swets 1966) proposes a separation between sensory (sensitivity or  $d'$ ) and decision factors (response bias or  $c$ ) in perception. Sensitivity measure starts from 0 (inability to discriminate) and increases with the improvement of discrimination ability; whereas response bias ( $c$ ) reflects liberal strategy when  $< 0$  (reporting stimuli as present even with a low certitude) and conservative strategy when  $> 0$  (reporting stimuli as present only with high certitude)—the optimal decision criterion being 0.



in Fig. 2A. These 300 trials consisted of 75 no distractor trials, 150 single-distractor trials (75 right, 75 left), and 75 double-distractor trials with two distractors symmetrically displayed (Fig. 2B). Distractor's contrast was the one yielding a  $d'$  close to 1 for each participant as determined in the *preliminary experiment 2*. After a speeded pointing response to the target (provided that this response was valid, i.e., with a reaction time within the range defined in the 1st preliminary experiment), participants selected one of the four perceptual responses by pressing the mouse buttons to indicate on the computer screen the perceived distractor(s): left present-right present, left present-right absent, left absent-right present, left absent-right absent (Fig. 2A). Immediately following the perceptual response, a feedback on the actual presence/absence of the distractor on each side was provided on the computer screen. This feedback was expected to prevent the participant from adopting a conservative strategy consisting in systematically answering "no" when (s)he was not fully aware of the presence of the distractor. In other words, this feedback was expected to reduce a positive response bias (i.e., a conservative behavior reflected by a criterion  $>0$ ) thereby decreasing the miss rate and increasing the FAs rate.

### Data recording and analysis

**PERCEPTUAL TASK. Discarded trials.** On average, 5.07% of the trials (range: 1–11.67%) were discarded during the experiment on the basis of RT criteria ( $<150$  ms or above the 95th percentile of the RT distribution obtained in *preliminary experiment 1*). Among these errors, 74.1% were late or no-go motor responses and 25.9% were anticipations.

**Sensitivity ( $d'$ ) and response bias ( $c$ ).** For each trial, two perceptual responses were considered, each one corresponding to one side of the target's location. Responses were classified as hits, misses, FAs, and CRs for each side. For example, if the participant reported left present and right present for a single distractor presented on the right of the target, both FA for the left side and hit for the right side were used to assess the overall sensitivity ( $d'$ ) and response bias ( $c$ ). The mean percentage of hit, miss, FA, and CR trials was, respectively,  $28.62 \pm 4.69$ ,  $19.18 \pm 4.21$ ,  $9.18 \pm 3.79$ , and  $39.88 \pm 3.49\%$  (means  $\pm$  SD).  $D'$  values varied in between 0.56 and 1.96 [ $1.18 \pm 0.45$ ; not significantly different from 1;  $t(9) = 1.28$ ,  $P = 0.23$ ];  $c$  values varied in between 0.18 and 0.61 ( $0.33 \pm 0.15$ ), which shows that despite the feedback, participants adopted a conservative strategy [ $t(9) = 7.11$ ,  $P < .01$  with respect to 0].

**MOTOR TASK. Spatial and temporal performances.** The beginning of a hand movement was defined as the first frame preceding peak velocity in which hand instantaneous velocity exceeded a 20 mm/s threshold. The end of the movement was defined using the same velocity threshold. We then measured RT, movement duration, and peak velocity. We also computed terminal angular error, i.e., the signed difference (in degrees) between the angles of the initial-to-terminal hand position vector and the starting position-to-target vector. Maximum curvature was defined as the signed maximum orthogonal distance between the movement trajectory and the initial-to-terminal hand position vector (i.e., the straight line connecting the initial to terminal hand positions). Mean curvature was defined as the mean of the signed distances between each point of the actual trajectory and its orthogonal projection on the initial-to-terminal hand position vector.

**Motor responses classification.** For each trial, motor responses were classified based on the four perceptual states, i.e., hit, miss, FA, and CR. To compare motor performances across these states, data were partitioned in two subsets: one including the no distractor and single-distractor trials and the other one including only the double-distractor trials. In the first subset (single and no distractor), a hit, miss, or FA on one side of the target was associated with a CR on the other side of the target (H+CR, M+CR, and FA+CR). The second

subset included single-hit (H+M), double-hit (H+H), and double-miss (M+M) trials. The data were then referred to CR (CR+CR) by subtracting the value measured on each trial from the average value of its spatially matched CR (left or right target). All the remaining trials (H+FA, M+FA, FA+FA) were not considered in the analysis as it was not possible in these trials to dissociate a mislocalized from a misperceived distractor.

**Motor responses analysis.** The effects of the distractor(s) on the parameters of the pointing movements (RT, movement time, peak velocity, terminal angular error, and curvature) were assessed for both single- and double-distractor conditions using one-way repeated measures ANOVAs. Post hoc analyses were performed using Scheffe test.

## RESULTS

### Reaction time

**SINGLE-DISTRACTOR CONDITION.** Relative RT was defined as the difference between RT for hit, miss, or FA and average RT for CR (baseline). A one-way repeated measures ANOVA showed a significant effect of the perceptual state [ $F(2,18) = 53.6$ ,  $P < 0.01$ ]. Post hoc analysis showed significant differences between hit ( $-30.48 \pm 13.84$  ms; mean  $\pm$  SD) and FA ( $-1.31 \pm 5.62$  ms) trials ( $P < 0.01$ ) as well as between hit and miss trials ( $+0.16 \pm 4.94$  ms;  $P < 0.01$ ). There was no difference between FA and miss trials ( $P = 0.91$ ). RT-hit was the only category of response significantly different from the baseline [ $t(9) = -6.97$ ,  $P < 0.01$ ]. Individual analysis was congruent with the group analysis as all participants showed a significant RT decrease in hit trials only ( $P < 0.01$  for nine participants and  $P < 0.05$  for the remaining one; see Fig. 3A).

**DOUBLE-DISTRACTOR CONDITION.** A one-way repeated measures ANOVA showed a significant effect of the perceptual state [ $F(2,18) = 36.69$ ,  $P < 0.01$ ]. Post hoc analysis revealed significant differences between RT-double miss ( $-6.25 \pm 6.11$  ms) and both RT-double hit ( $-41.22 \pm 15.54$  ms) and RT-single hit ( $-30.34 \pm 15.09$  ms). The difference between RT-double hit and RT-single hit was marginally significant ( $P = 0.056$ ). RTs in double-hit, single-hit, and double-miss trials were all significantly different from the baseline ( $P < 0.01$ ; see Fig. 3B). At the individual level, RT-double hit and RT-single hit were significantly different from the baseline for all the participants ( $P < 0.01$ ) except two participants who showed, respectively, only a tendency for significance in RT-single hit ( $P = 0.057$ ) and in RT-double hit ( $P = 0.050$ ). RT-double miss was, however, significantly different from the baseline for only three participants. Interestingly, the contrast values of the distractors were the highest for these three participants (33, 34, and 35%). Moreover, RT-double-miss and contrast values were highly correlated across participants ( $r = -0.89$ ,  $P < 0.01$ ).

In short, the present RT analysis indicates that pointing movements were facilitated by the distractor(s) when it/they was/were both physically present and consciously perceived (hit). When two distractors were present, the mere detection of only one of them entailed a RT facilitation. The facilitation effect was, however, stronger when the two distractors were both present and detected. A small facilitation effect was also observed when the two displayed distractors remained undetected (double miss).

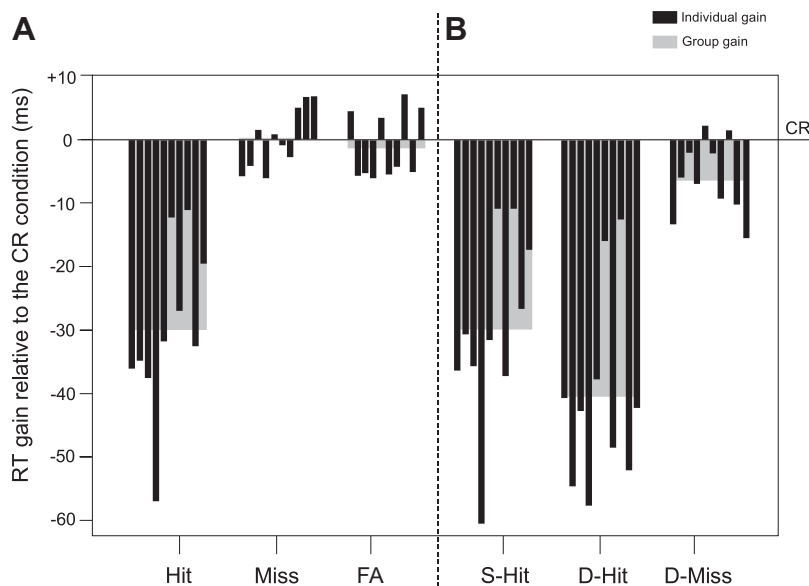


FIG. 3. Mean reaction time (RT) gain according to the correct rejection trials for single (A: hit, miss, false alarm) and double (B: single hit, double hit, double miss) distractor conditions. Dark bars represent individual performances; grey bars represent the average performance for the whole participants.

### Terminal angular error (TAE)

**SINGLE-DISTRACTOR CONDITION.** Relative TAE was analyzed for hit+CR, miss+CR, and FA+CR trials, with the mean TAE on CR+CR trials as a baseline. A one-way repeated measures ANOVA revealed a significant effect of the perceptual state [ $F(2,18) = 84.28, P < 0.01$ ]. Post hoc analysis revealed significant differences in TAE between hit ( $1.33 \pm 0.31^\circ$ ) and both FA ( $-0.16 \pm 0.29^\circ, P < 0.01$ ) and miss trials ( $0.09 \pm 0.29^\circ, P < 0.01$ ). TAE did not differ between FA and miss trials ( $P = 0.15$ ). TAE was different from the baseline only in hit trials [ $t(9) = 13.40, P < 0.01$ ]. This pattern of results was observed for each participant ( $P < 0.01$  for 7 participants and  $P < 0.05$  for 3 participants; see Fig. 4A).

**DOUBLE-DISTRACTOR CONDITION.** TAE for single-hit trials was assessed separately from double-hit and -miss trials. Spatial errors for double-miss and -hit trials were assessed using absolute angular errors relative to CR trials because deviation toward or away from the distractor could not be analyzed in these trials.

Mean TAE for single-hit trials was  $1.29 \pm 0.31^\circ$  toward the perceived distractor [ $t(9) = 13.38, P < 0.01$ ]. No significant TAE was observed for double-hit and -miss trials (respectively,  $0.17 \pm 0.49; P = 0.31$  and  $0.05 \pm 0.23; P = 0.53$ ; see Fig. 4B). Individual analysis was congruent with group analysis as eight participants showed trajectory deviation toward the perceived distractor in single-hit trials ( $P < 0.05$ ), the two remaining participants showing a tendency for significance ( $P = 0.056$  and  $P = 0.061$ ). No trajectory deviation was observed in the other conditions in both groups and individual analysis. A deviation of the trajectory toward the distractor was thus observed only when the distractor was physically present and reported (Fig. 4A).

Congruent with RT analysis, TAE analysis indicates that distractors affected participants' manual pointing responses when they were both present and detected. Given the deviations observed in the single-distractor hit trials, the lack of trajectory deviations in double-hit trials most likely resulted from the opposite effects associated with the presence of two distractors.

### Movement kinematics

No effect of the presence/absence or the detection/non-detection of the distractor on peak velocity, movement time, mean and maximum curvature was found using one-way repeated measures ANOVA in both single (hit, miss, FA)- and double-distractor conditions. Thus the distractor effect reported in the preceding text on RT and TAE was not observed for movement kinematics and trajectory curvature, suggesting that the main effect of the distractor occurred prior to the onset of the pointing movement (deviation of the terminal endpoint without curvature).

### DISCUSSION

The aim of the present study was to test the relation between the conscious perception of a close to threshold distractor and the early visual process that causes manual pointing movement to deviate toward a visual distractor. On each trial of the present experiment, participants performed a fast pointing movement toward a highly visible target followed by a perceptual judgment about the presence/absence of a near threshold distractor located on the right and/or the left of the target. The main outcome of the study is a robust RT facilitation effect and a deviation of the movement endpoint toward the distractor when this distractor was both physically present and consciously perceived in both single (hits)- and double-distractor (single hits: H+M, double hits: H+H) conditions. Models that attempt to account for distractor effects on eye or hand movements postulate that distractors generate spatially localized activation, presumably in the superior colliculus, that irrepressibly attracts the pointing/reaching trajectory toward the distractor (Arai and Keller 2005; Godijn and Theeuwes 2002; Quaia et al. 1998; Song and Nakayama 2006, 2008; Tipper et al. 2001; Walton et al. 2005). According to Tipper et al. (1997, 2001), target selection depends on the activity of a population of neurons in a visuomotor map. When target and distractor(s) are in close proximity (Theeuwes et al. 1998), the weighted average value of the different activities on the visuomotor map provides a terminal endpoint of the movement located between the target and the distractor, and would thus account for the

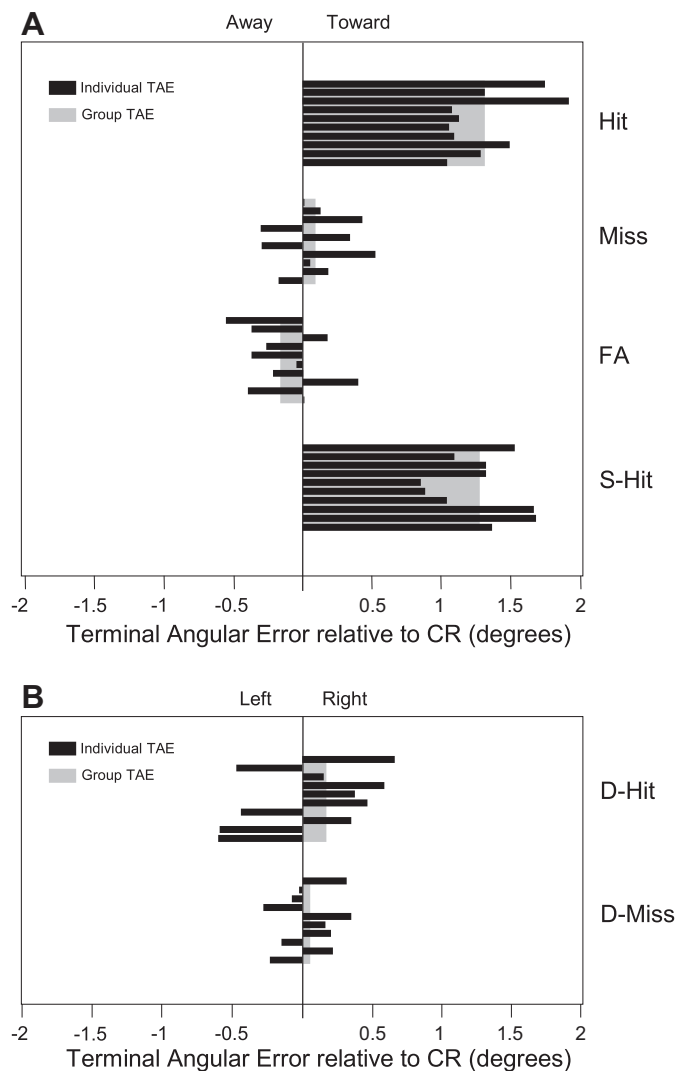


FIG. 4. Mean terminal angular error (TAE) relative to the average performance in the correct rejection (CR) trials. *A*: signed deviations in hit and miss trials according to the *displayed* distractor, signed deviation in false alarm trials according to the *falsely perceived* distractor, signed deviation in single-hit trials according to the *perceived* distractor (positive values for deviations toward, negative values for deviations away). *B*: signed deviations in double-hit and double-miss trials according to CR trials (*left*: negative values for deviations, *right*: positive values for deviations). Dark bars represent individual performances; grey bars represent the average performance for the whole participants.

so-called “global effect” (Findlay 1982; Sailer et al. 2002a,b). In agreement with this model, we found that movements deviated toward the distractor but only when the distractor was perceived and present. Furthermore, pointing movements did not deviate from their target when two distractors were simultaneously presented symmetrically around the target’s location (and detected) presumably because two symmetrical activations cancelled out each other (Cardoso-Leite and Gorea 2009; McSorley et al. 2004). As no variation of RT and movement endpoint was observed when the distractor was physically present but not consciously detected (miss trials: M+CR), these results argue also against claims that the motor system is generally influenced by visual information not available for conscious report (Amundson and Bernstein 1973; Binsted et al. 2007; Cressman et al. 2007; Ogmen et al. 2003; Taylor and McCloskey 1990; see also a

recent review by Mulckhuysse and Theeuwes 2010). Nevertheless we observed a small RT facilitation effect when two distractors were physically present but not consciously detected (double miss). Interestingly, this effect was dependent on the physical contrast of the distractor yielding an individual  $d'$  near 1<sup>2</sup>, a result in line with previous work using high contrast close to threshold visual stimulations<sup>3</sup> (Waszak and Gorea 2004; Waszak et al. 2007). In these studies, the authors assessed the effect of high and low contrast primes while keeping their visibility constant (by varying masking strength) and showed that low contrast primes entailed a perceptuo-motor coupling (i.e., effect on hits only), while a dissociation between perceptual and motor responses was observed with high contrast primes (i.e., effects on hits *and* misses).

Taken together, these results support the theory positing that perceptual and motor decisions are based on a common signal in the early process subtending target selection within the visual system—these decisions emerging from a contrast dependent fixed threshold for motor responses and a variable context dependent threshold for perceptual responses (Cardoso-Leite and Gorea 2010; Waszak and Gorea 2004; Waszak et al. 2007). These results also underline the impact of the experimental conditions in which motor effects elicited by “unconscious” visual stimulations are observed (for a review, see Cardoso-Leite and Gorea 2010). In particular, the physical energy of the stimuli seems to play an important role in the motor effects observed in the presence of “invisible” primes or distractors. Indeed, previous studies showing subliminal effects generally used full contrast stimuli associated with a high contrast mask (see Amundson and Bernstein 1973; Binsted et al. 2007; Cressman et al. 2007; Ogmen et al. 2003; Taylor and McCloskey 1990). Furthermore it is noteworthy that contrary to the present paradigm, most of these studies assessed perceptual and motor responses within separate blocks of trials (i.e., not on a trial-by-trial basis) and involved more complex perceptual responses than a simple detection task (see Cardoso-Leite and Gorea 2010).

Using an experimental paradigm similar to the present one (i.e., near threshold low contrast distractors, detection task and both perceptual and motor responses assessment on a trial-by-trial basis), Cardoso-Leite and Gorea (2009) observed that saccadic eye movements curved *away* from a near threshold distractor as long as the latter was detected, but regardless of its physical presence (i.e., hits *and* FAs). Their results thus support the existence of a perceptual state dependent reactive inhibition process (i.e., deviations away depending merely on the detection—even false—of the distractor). As trajectory deviations *away* from distractors are thought to result from a reactive inhibition mechanism operating on the early excitatory process (Tipper et al. 1997, 2001; Van Der Stigchel et al. 2006) then trajectory deviations toward a perceived distractor were

<sup>2</sup> No correlation was found between individual reaction time facilitation in double-miss trials and individual  $d'$  values: hence this facilitation effect should be attributable to the physical contrast of the distractor and not to the individual sensitivity.

<sup>3</sup> It is noteworthy that, as two distractors were physically present in double-miss trials, one can consider that the contrast of the “global priming signal” was larger in these cases. The close to significance difference between RT double hit (around -40 ms) and RT single hit (around -30 ms) is in line with this assumption.



expected in our study (i.e., also in FA trials). This was not the case, however. As we presumably tested the effect of visual distractors in an earlier stage of movement programming than did Cardoso-Leite and Gorea (2009), this incongruency suggests that FAs occur at the inhibitory stage of visual processing and are not yet “built” in the preceding excitatory phase. Alternatively or jointly, the experimental conditions used in this study may have also weakened a potential effect in FA trials. First, as the low distractors’ contrast (~30%) already entailed a small trajectory deviation in hit trials (1.33° toward the distractor though separated by 30° from the target), the effect of the distractor in FA trials was expected to be small.<sup>4</sup> Furthermore, performing movements without visual feedback of hand’s position may also have significantly increased the variability of trajectories (Desmurget et al. 1997) and weakened the deviation effect in FA trials.

Another incongruency between the present study and that of Cardoso-Leite and Gorea’s (2009) concerns the distractor effect on RTs. Cardoso-Leite and Gorea (2009) did not find any distractor effect on oculomotor latencies, while the presently recorded pointing latencies were ~30 ms shorter (relative to CR trials) in both the single- and double-distractor hit trials. This difference may be accounted for by the characteristics of the stimuli used in the two studies. In the present study, target and distractor(s) were spatially compatible, i.e., in close proximity and in the same hemifield. In Cardoso-Leite and Gorea’s setup, the target was presented on the central meridian and distant from the distractors’ location. The present results are thus in line with previous findings showing that the presentation of a compatible distractor just before a target reduces manual reaching RTs (Bock and Arnold 1992; Bock and Eversheim 2000; Pellizzer and Hedges 2003, 2004). They are also in agreement with studies showing a RT reduction to a suprathreshold target by near threshold distractors only when consciously detected (Waszak and Gorea 2004; Waszak et al. 2007).

The substantial facilitation effect on RT may also reflect a bias associated with the SOA used. Indeed, despite its low contrast, the distractor could have competed with the target so that reaching movements were initiated toward the distractor and then corrected mid-flight to reach the target. Several elements argue, however, against this interpretation. First, the instruction given to the participants was straightforward (i.e., never reach any other stimulus but the target) and the relative spatial and temporal characteristics of the stimuli did not vary across the trials. There was consequently no ambiguity concerning the goal of the task and the relevant stimulus. Second, assuming that the initial part of the trajectory was directed toward the distractor and then corrected mid-flight, trajectory patterns for hit trials should have been characterized by an increase of trajectory curvature. The absence of any effect of the experimental conditions on trajectory curvature invalidates the interpretation according to which participants responded toward the distractor considered initially as the target. We propose that the most likely account of the present RT effect is that the distractor initially acted as a prime facilitating the response toward the target’s location by providing a temporal

cue on its occurrence. The fact that RT and angular error effects were not correlated argues in favor of this interpretation and implies that these two distractor effects are independent (Cardoso-Leite and Gorea 2009; McSorley et al. 2004; Walker et al. 2006). Such independency can be accounted for by positing that a priming distractor effect occurs at the very early stage of visual processing and facilitates the triggering of the motor response, and the spatially specific activation evoked by the distractor occurs later in time and biases target selection for action (global effect).

In conclusion, this study provides evidence against a compulsory effect of not perceived stimulations on motor responses. The present results are in line with the notion of a common signal for perceptual and motor decisions in the early process subtending target selection within the visual system (Waszak and Gorea 2004; Waszak et al. 2007) and thus generalizes the proposal of a unique signal for perception and action to different motor effectors by extending to hand movements previous observations obtained with manual RTs and saccadic eye movements (Cardoso-Leite and Gorea 2009; Waszak and Gorea 2004). Further investigations remain, however, necessary for a better understanding of the relation between perception and action at the different stages of target selection. In particular, the present study raises several open questions concerning: the influence of FAs on motor planning, the perceptuo-motor relationship assessed for different components of a motor response (i.e., latency and trajectory deviation), and the factors putatively modulating this relationship among which the physical energy of the stimulation, the type of response, and the characteristics of the task.

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#### DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the author(s).

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<sup>4</sup> The saccade deviation observed in Cardoso-Leite and Gorea’s experiment (2009) excitatory postsynaptic potential) was more than three times smaller in the FA than in the hit trials.

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