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What is This?

Research Report

An Attentional Mechanism for Selecting Appropriate Actions Afforded by Graspable Objects

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ABSTRACT—*An object may afford a number of different actions. In this article, we show that an attentional mechanism inhibits competing motor programs that could elicit erroneous actions. Participants made a speeded key press to categorize the second of two successively presented door handles that were rotated at varying orientations relative to one another. Their responding hand was compatible or incompatible with the graspable part of the door handles (rightward or leftward facing). Compatible responses were faster than incompatible responses if the two handles shared an identical orientation, but they were slower if the two handles were aligned at slightly dissimilar orientations. Such suppressive surround effects are hallmarks of attentional processing in the visual domain, but they have never been observed behaviorally in the motor domain. This finding delineates a common mechanism involved in two of the most important functions of the brain: processing sensory data and preparing actions based on that information.*

The visual presentation of a graspable object can activate perceptual and motoric representations. For example, the visual presentation of a horizontally aligned door handle activates neurons in primary visual areas that code for lines of similar orientations. This orientation-selective activation propagates forward through the extrastriate cortex to the anterior motor and premotor regions of the brain so that an appropriate grasping movement can be prepared. Thus, if a person sees a door handle with the graspable part facing towards the right, it will make them faster to respond with their right (response-compatible) hand than with their left (response-incompatible) hand in an

unrelated task (Tipper, Paul, & Hayes, 2006; Tucker & Ellis, 1998). Action-relevant properties of the stimulus such as its size or orientation have been shown to prime associated components of the afforded action such as grasp aperture or wrist rotation (Ellis & Tucker, 2000).

The brain is faced with two problems as the perceptual information flows from primary visual cortex to extrastriate and anterior cortical areas. First, orientation-selective neurons in higher visual areas (e.g., V4) have larger receptive fields than those in early visual areas (e.g., V1 and V2) and receive input from a range of different orientations (Desimone & Schein, 1987; Levitt, Kiper, & Movshon, 1994). Second, the brain is composed of neuronal hierarchies with many-to-one mappings such that a single neuron activated in one level (e.g., V1) will activate many more in the level above (e.g., V2), causing an exponentially increasing spiral of activity (Tsotsos, 1990). In the absence of a control mechanism, this "blurring" of activation would lead to the unfocused activation of neurons coding for many different orientations in higher visual areas, even though the door handle is providing perceptual input of only a single orientation. Each activated visual orientation would, in turn, activate premotor circuits coding for a grasp in that orientation. The concomitant diffuse activation of premotor circuits would result in the generation of multiple motor programs in many different orientations. This would impede the preparation and selection of the appropriately oriented grasp.

In the field of visual attention, the selective-tuning model of attention specifically addresses blurring and other information flow problems in the brain (Tsotsos et al., 1995). The model instantiates a winner-takes-all competition at the top of a neuronal hierarchy that inhibits any connections in the level below that do not contribute to the winner. This allows only those neurons that code for features and the location of an attended stimulus to contribute to activation at the response level and inhibits neurons coding for similar features and locations that have been activated as a result of blurring. The model predicts

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that the facilitatory spotlight that has been used as an analogy of attention should have an inhibitory annulus. The existence of this annulus has been observed in both the spatial and feature domains (Caputo & Guerra, 1998; Cutzu & Tsotsos, 2003; Hopf et al., 2006; Müller & Kleinschmidt, 2004). For example, human participants are slower to make perceptual judgments about stripes of a particular orientation when they have previously attended to stripes of a slightly dissimilar orientation than they are to make judgments about stripes with very dissimilar orientations (Tombu & Tsotsos, 2008). If a center-surround mechanism, such as selective tuning, that is purported to focus attention in the visual system extends into the motor system, then we should find evidence of the inhibitory annulus in the action system or, more specifically, in the selection of motor programs for action.

To test this hypothesis, we developed a behavioral task that relies on the rationale that a graspable object activates a suitable motor program, which is expressed in facilitated responses with the hand that is compatible with the graspable part of the object. We briefly presented pictures of door handles: a prime handle followed by a probe handle (see Fig. 1). The orientation of the two handles varied by $0°, 20°, 40°,$ or $60°$ relative to one another, but the probe handle was always presented in a horizontal orientation. Participants made speeded key-press responses to the probe handle. Each responding hand was assigned a response key, so that it was either compatible or incompatible with the door handles, which faced to the right or left. We predicted that presentation of the prime handle would elicit the generation of a motor program suitable for a reach of that orientation. Center-surround inhibition associated with this motor program should inhibit other motor programs coding for slightly dissimilar reaches (i.e., $20°$ or $40°$ difference in orientation). Thus, if the subsequently presented probe handle elicits a reach within that
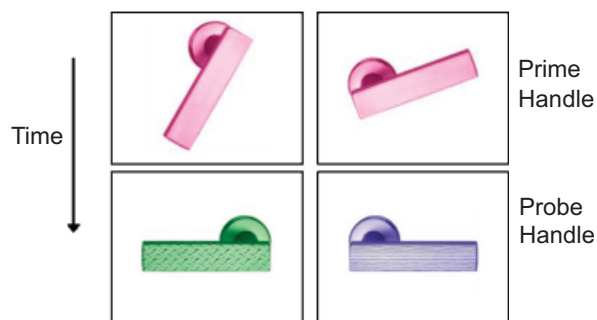
Fig. 1. Example of prime and probe door handles in two types of trials. Participants responded either to the texture (Experiment 1) or to the color (Experiment 2) of the probe handle. The column on the left shows a trial in which the orientation of the prime handle differs from the orientation of the subsequently presented probe handle by $60°$. The probe handle (always horizontal) is green and has a diamond-plate metal texture, and the compatible responding hand is the left hand. The column on the right shows a trial in which the orientation of the prime handle differs from the orientation of the subsequently presented probe handle by $20°$. The probe handle is blue and has a wood-grain texture, and the compatible responding hand is the right hand.

range, it would require the activation of a recently inhibited motor program.

We compared reaction times (RTs) on response-compatible trials to RTs on response-incompatible trials for each difference in orientation between prime and probe handles. This provides a pure measure of motor attention unaffected by visual factors such as masking of the probe handle. This is the same principle as subtracting out cued from uncued trials in a classic spatial cueing task, yielding a pure measure of visual attention unaffected by retinal eccentricity, for example (Posner, 1980). In the present task, the responding hand rather than a spatial location is cued. By this rationale, faster RTs in response-compatible (cued) trials than in response-incompatible (uncued) trials reflect facilitation, whereas slower RTs in response-compatible trials than in response-incompatible trials reflect inhibition (cf. Posner & Cohen, 1984). Thus, center-surround inhibition associated with the activation of the prime handle motor program should lead to a delay in responding to the probe handle with the compatible hand, relative to the incompatible hand, if the orientation of the prime and probe handles differs slightly, as opposed to when the orientations are identical or very dissimilar.

To determine whether any inhibitory surround effects we may obtain are indeed due to inhibition of competing motor programs and are not merely due to visual factors, we varied which attribute of the probe handle was to be reported. Tipper et al. (2006) showed that effects of affordance depend on whether or not an action relevant property of the object is attended. They obtained response-compatibility effects when participants discriminated the shape of a door handle, but not when they discriminated the color of the same object. In Experiment 1, participants responded to the probe handle by pressing one of two keys corresponding to its texture. In Experiment 2, participants responded to the probe handle by pressing one of two keys corresponding to its color. Texture is a tactile, and therefore action-relevant, dimension whereas color is not (e.g., Fikes, Klatzky, & Lederman, 1994). The activation of motor programs should be contingent on whether or not an action-based dimension of the handles is attended. Thus, we should observe an effect of compatibility in the texture task, but not in the color task.

EXPERIMENT 1

Method

Twenty university undergraduates (4 males, 16 females; mean age = 20.5 years, range = 18–25 years) took part in exchange for course credits. The experiment consisted of 10 practice trials followed by 392 experimental trials. The trial sequence was as follows: The participant viewed a fixation cross (900 ms), followed by the prime handle (300 ms), a blank screen (300 ms), and the probe handle (duration until response). Door handles could subtend up to $12.3°$ by $12°$ of visual angle at the pre-

scribed viewing distance of 57 cm. The prime handle was pink and had a smooth texture. The horizontally aligned probe handle was either blue or green and had either a diamond plate metal or wood grain procedural texture. The orientation of the prime handle could differ from the probe handle by $0°$, $20°$, $40°$, or $60°$ in an upward or downward direction rotated around the center of the image. All orientations of the prime handle were shown an equal number of times. The graspable part of both the prime and probe door handles always faced towards the same side on any given trial (either to the left or the right). Participants made a speeded response to the texture of the handle (diamond plate metal or wood grain). The mapping of the response keys (z and , on a QWERTY keyboard) to *wood* or *metal* was counterbalanced across participants.

Results and Discussion

RTs were only analyzed if the participant correctly categorized the probe handle. Errors occurred on only 3% of trials. Repeated measures analyses of variance (ANOVAs) were carried out on the accuracy data and on median RTs to assess the interaction between the compatibility of the handles with the responding hand and the difference in orientation between the prime and probe handles. Planned comparisons between response-compatible and response-incompatible trial types at each difference in orientation yielded our measure of motor attention.

Analysis of the accuracy data revealed no significant effects (all $ps > .37$, all $p_{rep}s < .59$). An ANOVA of the RT data in terms of the rotation of the prime handle (upward vs. downward) revealed no significant effect of this variable (all $ps > .33$, all $p_{rep}s < .62$), which was collapsed in the subsequent analyses. As shown in Figure 2a, differences between RTs in response-compatible and response-incompatible trials varied as a function of orientation, $F(3, 57) = 7.13$, $p < .001$, $p_{rep} > .99$, $\eta_p^2 = .27$. Participants responded significantly faster with the compatible hand (relative to the incompatible hand) if prime and probe handles shared an identical orientation: $0°$ difference, $t(19) = 2.41$, $p = .026$, $p_{rep} = .92$, $d = .15$. In contrast, RTs in the response-compatible trials were significantly slower than the RTs in the response-incompatible trials when the two handles were aligned at slightly dissimilar orientations: $20°$ difference, $t(19) = -3.32$, $p = .004$, $p_{rep} = .97$, $d = 0.25$; $40°$ difference, $t(19) = -2.57$, $p = .019$, $p_{rep} = .93$, $d = 0.17$. As the difference in orientation increased ($60°$), the compatibility effect disappeared ($t < 1$). These results are consistent with the hypothesis that a center-surround mechanism inhibits competing motor programs elicited by the prime handle.

EXPERIMENT 2

Method

Twenty new university undergraduates (6 males, 14 females; mean age = 20.5 years, range = 18–27 years) took part in exchange for course credits. All aspects of the stimuli and procedure were identical to Experiment 1, except that participants indicated the color rather than the texture of the probe handle. The mapping of the response keys (z and ,) to *blue* or *green* was counterbalanced across participants.

Results and Discussion

Errors occurred on 4% of trials. Analysis of the accuracy data revealed no significant effects (all $Fs < 1$). The direction of rotation of the prime handle (upward or downward) did not influence the results (all $ps > .33$, all $p_{rep}s < .62$), and this variable was collapsed in subsequent analyses. As can be seen in Figure 2b, RTs did not vary as a function of compatibility or orientation ($F < 1$). Furthermore, no significant differences emerged between response-compatible and response-incompatible trials at any orientation (all $ps > .21$, all $p_{rep}s < .72$). Note that the only difference between the texture and color tasks was the response dimension of the probe handle; the stimuli were perceptually identical. Thus, these results suggest that the suppressive surround effect observed in the texture task was independent of visual factors such as the spatial proximity of the prime and probe handles at different orientations, and it can therefore be attributed to a motor effect.

GENERAL DISCUSSION

The results of these experiments suggest that perceived objects involuntarily activate many potential motor programs that subsequently compete with one another to be selected when the brain is attending to an action-relevant dimension. The winner of this competition receives facilitatory activation, whereas the losers (i.e., programs that code for similar yet erroneous actions) receive inhibitory feedback, hence the suppressive surround effect.

The implication of this finding is that a common attentional mechanism, center-surround inhibition, is aiding selection in both the action and the perceptual systems of humans. This provides insight into how information can successfully traverse the neuronal architecture of the brain and result in interactions between action and perception. One of the prominent theories of such interactions, the premotor theory of attention, holds that activation from motor programs that are generated in anterior premotor regions of the brain travels via feedback connections to posterior visual areas that code for locations or features that are congruent with that motor program, thus facilitating visual processing (Rizzolatti, Riggio, Dascola, & Umiltà, 1987). For example, it has been shown that the preparation of a specific grasping movement reduces the time required to detect and discriminate a visually presented object if its action-relevant properties, such as shape or orientation, match the prepared grasp (Craighero, Fadiga, Rizzolatti, & Umiltà, 1999). We believe it is likely that the motor-based inhibitory annulus

a

b
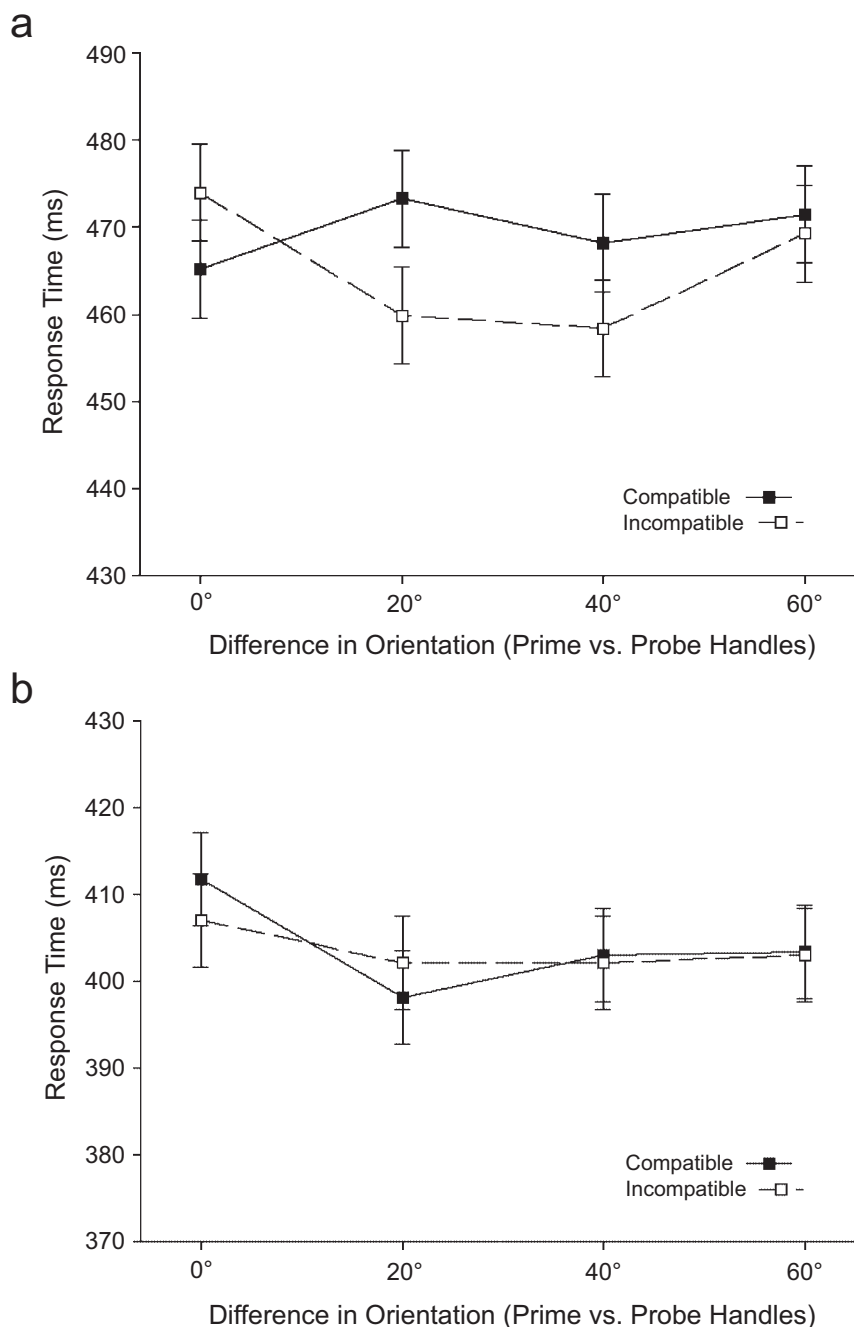
Fig. 2. Measures of motor attention in different tasks: the texture task in Experiment 1 (a) and the color task in Experiment 2 (b). Means of median response times (y-axis) are displayed as a function of the difference in orientation between the prime and probe handles (x-axis). Results are shown separately for responses with the compatible hand and responses with the incompatible hand. Error bars indicate within-subjects 95% confidence intervals (Loftus & Masson, 1994).

observed in the present study forms an integral part of the top-down signal that biases visual attention.

It should also be noted that people with autism-spectrum disorders often suffer from poor motor coordination and visuomotor integration, as well as abnormalities in visual attention such as delayed spatial orienting (e.g., Allen, & Courchesne,

2001; Mari, Castiello, Marks, Marraffa, & Prior, 2003). Furthermore, patients with schizophrenia typically exhibit poor motor planning and a lack of inhibition of inappropriate responses as well as deficits in inhibiting irrelevant visual information (Braff, 1993; Kiehl, Smith, Hare, & Liddle, 2000). If selection of visual information and of motor programs is

mediated by similar attentional mechanisms, as we propose, dysfunction of this mechanism might contribute to these deficits.

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