Journal of Experimental Psychology:
Human Perception and Performance
2012, Vol. 38, No. 2, 279–284

0096-1523/12/$12.00 DOI: 10.1037/a0026658

OBSERVATION

Do Endogenous and Exogenous Action Control Compete for Perception?

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Human actions are guided either by endogenous action plans or by external stimuli in the environment. These two types of action control seem to be mediated by neurophysiologically and functionally distinct systems that interfere if an endogenously planned action suddenly has to be performed in response to an exogenous stimulus. In this case, the endogenous representation has to be deactivated first to give way to the exogenous system. Here we show that interference of endogenous and exogenous action control is not limited to motor-related aspects but also affects the perception of action-related stimuli. Participants associated two actions with contingent sensory effects in learning blocks. In subsequent test blocks, preparing one of these actions specifically impaired responding to the associated effect in an exogenous speeded detection task, yielding a blindness-like effect for arbitrary, learned action effects. In accordance with the theory of event coding, this finding suggests that action planning influences perception even in the absence of any physical similarities between action and to-be-perceived stimuli.

Keywords: action control, effect anticipation, action-induced blindness, endogenous versus exogenous

Most human actions can be characterized as intentional, goal-directed, and guided by endogenous action plans. In addition to such endogenously generated actions, humans are capable of abandoning current action plans to react instantly to environmental demands. This distinction of endogenous and exogenous action control has stimulated an impressive number of studies over the past decades. Even though the ultimate motor output of endogenously and exogenously driven actions might appear identical, numerous neuroimaging studies suggest that the two types of actions are implemented differently on the neural level (e.g., Jahanshahi et al., 1995; Rowe, Hughes, Nimmo–Smith, 2010; Wiese et al., 2004). These studies converge on the notion of a stronger involvement of frontal midline structures and posterior parietal areas in endogenous than in exogenous actions, indicating a partial dissociation of the two systems.

From a conceptual point of view, however, the definitions of “endogenous” and “exogenous” actions vary substantially between studies. For the following argument, we will therefore adopt the most basic distinction possible: An exogenous action is “made immediately in response to an imperative external cue” (Obhi, Matkovich, & Chen, 2009, p. 2756) whereas we consider all other actions to be endogenous without further subdivisions (see Brass & Haggard, 2008, for a more detailed approach). Recent behavioral studies demonstrated that such endogenous and exogenous actions might interfere with each other when they share certain features (Stoet & Hommel, 1999; Fournier et al., 2010) or aim at producing identical behavioral output (Obhi & Haggard, 2004; Obhi et al., 2009). In other words, endogenously preparing an action even impairs the performance of this particular action in response to a sudden imperative stimulus—thus by definition an exogenous action (Astor–Jack & Haggard, 2005; Obhi & Haggard, 2004). Competition between endogenous and exogenous actions may, however, not be limited to processes that control immediate motor output. Instead, several studies suggest that endogenously preparing an action has a profound impact also on perceptual processes that, in turn, might directly affect the exogenous system (Wühr, 2006).

The impact of endogenous action preparation on concurrent perception is most evident in the phenomenon of action-induced blindness (Müsseler & Hommel, 1997a, b; Nishimura & Yokosawa, 2010; Stevanovski, Oriet, & Jolicoeur, 2006; Thomaschke, Hopkins, & Miall, in press). In a seminal study on action-induced blindness, Müsseler and Hommel (1997a) had their participants

This article was published Online First December 26, 2011.

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We thank Lisa Fournier and Chris Oriet for their helpful comments on a previous version of the manuscript.

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perform two tasks. As a primary task, participants prepared a left or right key press according to a response cue. Before executing the prepared key press, however, they had to press both keys simultaneously what triggered a masked left- or right-pointing arrow. As a secondary task, participants had to identify the direction of this masked arrow. The prepared action had a profound impact on the secondary identification task: Identification performance was impaired when the direction of the prepared action and the arrow matched rather than differed. In other words, endogenously preparing an action impaired the identification of stimuli with overlapping physical properties.[1]

Such action-induced blindness might impair performance when the to-be-detected stimulus demanded for an immediate reaction mediated by the exogenous system, because the stimulus representation has to be released from the endogenous action plan first. Testing this prediction was one of two goals of the present experiment. In the following, we will outline the theoretical framework leading to this prediction. This account also gives rise to the second goal of the present experiment, namely investigating whether or not blindness-like phenomena generalize to learned distal action effects.

The phenomenon of action-induced blindness is explained parsimoniously by the theory of event coding (TEC; Hommel, Müsseler, Aschersleben, & Prinz, 2001). This framework relies on the idea that action and perception are represented in a common code (Prinz, 1997) and that actions are addressed in terms of their sensory consequences (Kunde, 2001; Pfister, Kiesel, & Melcher, 2010; cf. Pfister & Janczyk, in press). Accordingly, preparing an action is nothing else but anticipating its sensory consequences. These anticipated effects can be proximal (proprioceptive) such as the feeling of having moved the left or right hand. Accordingly, preparing a left action occupies a "left" code (Stoet & Hommel, 1999). This *code occupation* renders the code unavailable to other processes, such as the subsequent perception of a left-pointing arrow (action-induced blindness; Müsseler & Hommel, 1997a, b; Stevanovski, Oriet, & Jolicoeur, 2003; Stevanovski et al., 2006; Thomaschke et al., in press). Proximal action effects, however, are not the only type of action effects that are integrated in action control. Instead, numerous studies suggest that distal action effects, such as visual or auditory effects, are also included in action control (Janczyk, Skirde, Weigelt, & Kunde, 2009; Kiesel & Hoffmann, 2004; Kunde, 2001), especially for endogenously controlled actions (Ansorge, 2002; Pfister et al., 2010). In fact, distal action effects have been ascribed a central role for action planning (e.g., Hommel et al., 2001; Janczyk et al., 2009).

Based on these findings, we predicted that action-induced blindness might not be limited to physical response–stimulus similarities, but might as well occur for any kind of proximal or distal action effects. Furthermore, we predicted that this mechanism might impair exogenous responses to an effect stimulus whenever the effect code is bound in an endogenous action plan. To test these two predictions, participants first learned the contingency between two actions (key presses) and their distinctive effects (stimulus onset or offset). In subsequent test phases they prepared one of these actions on each trial (primary task). Before actually executing the action, however, they had to respond to the occurrence of one of the two (learned) effects with a speeded response (see Figure 1). In other words, one of the previously learned effects served as the imperative stimulus in an exogenously driven detection task (secondary task). We expected reaction times (RTs) in this task to be prolonged if the to-be-detected stimulus matched the learned action effect of the endogenously prepared action—reflecting the process of unbinding this feature from the endogenous action plan and making it accessible to the exogenous system.

Method

Twenty-two students (3 males; mean age 23.3 years) participated for monetary compensation. They responded on a computer keyboard with the right index- and middle-finger on the keys *O* and *P* (primary task), and the left index-finger on the spacebar (secondary task). Stimuli were capital letters scattered across a visual search display. The experiment consisted of eight blocks: four learning and four test blocks in alternating order, beginning with a learning block.

Learning Blocks

Trials started with a central fixation cross (500 ms) followed by a blank screen (500 ms). Then, 10 randomly drawn capital letters appeared at random positions within an invisible 6×6 matrix. The only restriction was that an *A* was always presented and an *E* was never presented. Participants were to press either the left (*O*) or the right (*P*) key at their leisure. They were instructed to avoid repeating patterns of key presses and to press both keys about equally often. Each key press resulted in an immediate, salient effect (1000 ms): Either an *E* appeared at a new random location (onset), or the *A* disappeared (offset). The mapping of these effects to the response keys was counterbalanced across participants. The intertrial interval was 1000 ms. The first learning block comprised 48 trials; all subsequent learning blocks comprised 20 trials.

Test Blocks

Each test trial started with a centrally presented arrow ($<$ or $>$; 1500 ms). Participants were instructed to prepare a left or right key press with their right hand, according to the direction of the arrow. While participants still prepared the initial action, 10 letters were presented in the same way as in learning blocks. Following a variable delay of 500 to 1000 ms (in steps of 100 ms), either an *E* appeared (onset) or the *A* disappeared (offset). Crucially, participants were to press the space bar as soon as they detected a change in the display. This detection response did not have any distinctive (distal) action effects in any condition. After the exogenously triggered detection response they performed the initially prepared key press in a nonspeeded manner. Each test block consisted of 48 trials.

Results

Participants chose both response keys about equally often during the learning blocks (all individual $\chi^2 \leq 1.82$, $p\text{s} \geq .18$). For the

[1] Action-induced blindness was initially labeled "action-effect blindness" (Müsseler & Hommel, 1997a). For the following argument, however, we prefer the label "action-*induced*" blindness (Müsseler, Wühr, Danielmeier, & Zysset, 2005) to stress that previous studies did not investigate blindness to learned distal action effects but refer to inherent (physical) similarities of proprioceptive action effects and action-unrelated stimuli (but see Stevanovski et al., 2003).

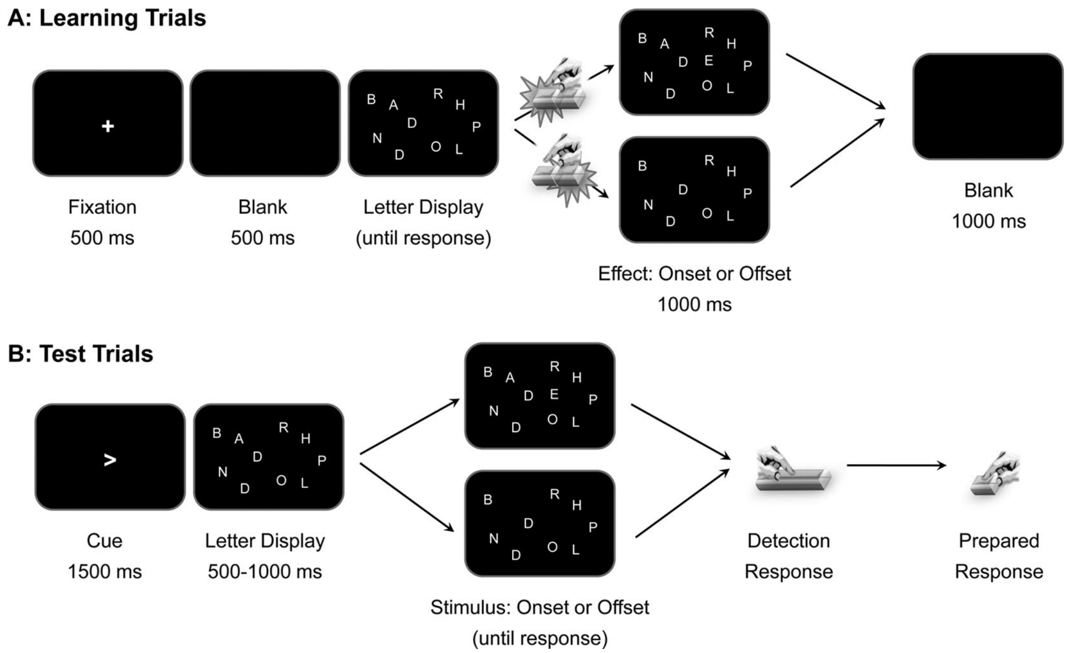

Figure 1. (A) In learning trials, participants chose between pressing a left or right key (with the index or middle finger of the right hand). This key press triggered a change in the display: Either an *E* appeared or the *A* disappeared. The action-effect mapping was constant so that participants could associate actions and resulting effects. (B) In test trials, participants prepared a left or right key press as indicated by a cue. Before executing this endogenously prepared action, however, they had to detect a change in the following display as quickly as possible by pressing the space bar (with the left index finger). The effect was always one of the two previously experienced action effects—either the effect that was associated with the prepared response ("anticipated stimulus") or the effect that was associated with the alternative response.

analysis of the test blocks, we excluded trials in which the prepared response was incorrect (1.8%) or in which the detection RT deviated from an individual's mean RT by more than 2.5 standard deviations (3.1%), calculated separately for each design cell.

Mean RTs of the detection task were subjected to an analysis of variance with stimulus type (onset vs. offset) and endogenous stimulus representation (anticipated vs. unanticipated) as repeated measures. Crucially, this analysis revealed slower detection responses if the stimulus was anticipated than when it was not (384 ms vs. 371 ms; Figure 2), $F(1, 21) = 11.08$, $p = .003$, $\eta_p^2 = .35$. Additionally, responses were slower to onsets than to offsets (389 ms vs. 366 ms), $F(1, 21) = 14.18$, $p = .001$, $\eta_p^2 = .40$, whereas the interaction of both factors did not approach significance ($F < 1$). A similar analysis on the data of the (unspeeded) prepared response did not show any effect for mean RTs (325 ms; Fs < 1) or accuracy (ps $> .196$).

Discussion

The present study investigated whether endogenous and exogenous action control compete for the perception of action-related stimuli. As hypothesized, participants were specifically impaired in a speeded stimulus detection task when the stimulus in question matched the learned action effect of an endogenously prepared action.[2] In line with prior behavioral studies on the interaction of endogenous and exogenous action control, we assume a switch from endogenous to exogenous action control to occur in each trial (Astor–Jack & Haggard, 2005; Obhi & Haggard, 2004). In addition to previously reported unspecific interference effects, we observed increased switch costs when the to-be-detected stimulus was endogenously represented as part of the prepared response (i.e., a specific interference effect; Müsseler & Wühr, 2002; see also Obhi, Matkovich, & Chen, 2009; Stevanovski et al., 2003).

These results have two important implications. First, they suggest that action-induced blindness phenomena are far more general than suggested by previous studies (Kunde & Wühr, 2004; Müsseler & Hommel, 1997a, b; Müsseler, Steininger, & Wühr, 2001; Oriet, Stevanovski, & Jolicoeur, 2007; Wühr & Müsseler, 2002). Whereas these studies investigated action-induced blindness for physical, hard-wired, and/or highly overlearned response-stimulus relations, we show that blindness-like phenomena may extend to any kind of stimuli as long as these stimuli resemble learned action effects.

[2] The reported blindness-like phenomenon was present for both kinds of action effects; still, offsets were detected faster than onsets. This finding might seem counterintuitive because studies on attentional capture have suggested that onsets are detected more easily than offsets (e.g., Miller, 1989). However, because in our experiment it was always the same letter that disappeared from the screen, participants had time to locate this letter beforehand. The location of an onset, in contrast, was unknown to the participants.

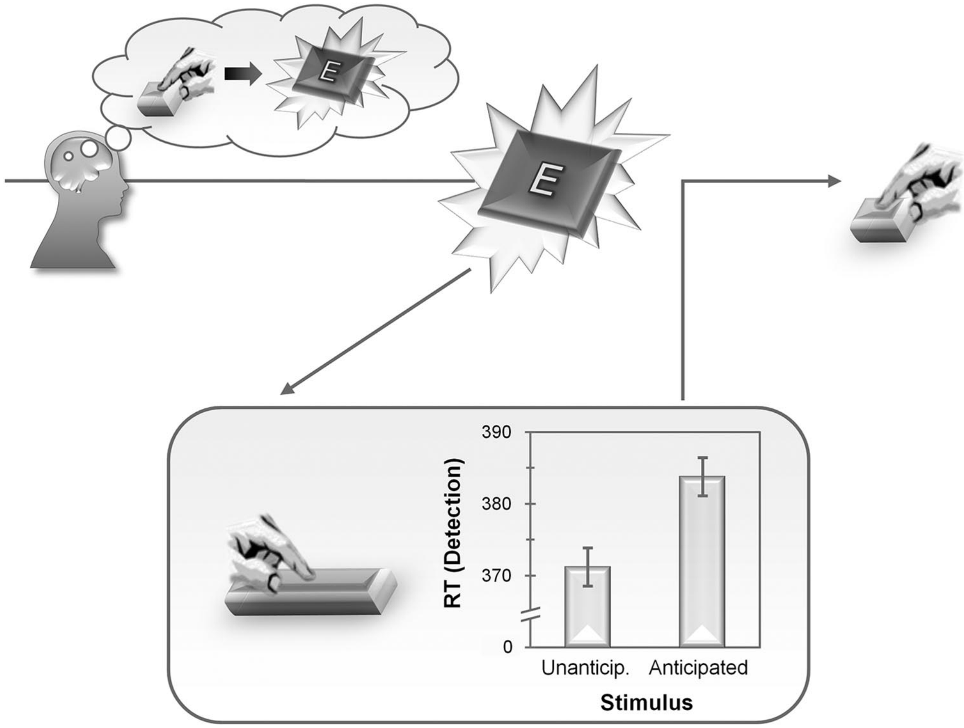

Figure 2. Schematic of the assumed processes taking place in test trials including the main results. The endogenous preparation of the response encompasses features of associated distal action effects, in this case the onset or offset of a particular letter. The code of this event is thus occupied and has to be released if this event suddenly prompts another (exogenously controlled) action. Accordingly, participants were slower in detecting a change in the display when this change corresponded to the anticipated action effect than when it did not. Error bars indicate within-subjects standard errors (Loftus & Masson, 1994).

As mentioned in the introduction, action-induced blindness can be explained in the framework of the TEC (Hommel et al., 2001). According to TEC, action plans are formed by binding feature codes of currently planned actions together and bound codes are unavailable to other processes (Stoet & Hommel, 1999; Wiediger & Fournier, 2008). Given that endogenously controlled actions are most likely to involve the anticipation of distal action effects (Ansorge, 2002; Pfister et al., 2010), the codes of these distal action effects will also be occupied and inaccessible for other processes. From a theoretical point of view, two different mechanisms are plausible to resolve this code occupation. TEC suggests that a currently bound code is shielded from other processes, so that perceptual processing of the exogenous stimulus cannot start until the corresponding event file has decayed (Akyürek, Riddell, Toffanin, & Hommel, 2007) or is actively unbound. Another possibility is that event file binding does not occur in an all-or-none fashion, implying that perception of the exogenous stimulus starts right away but is slowed down due to the existing binding (for an integrative perspective, see Hommel, 2004, 2005).

These mechanisms can also be interpreted in terms of a simpler sensorimotor stage model that assumes a sequence of a perceptual stage, a capacity-limited central stage, and a motor execution stage (Pashler, 1994; Sanders, 1980). Findings from the psychological refractory period (PRP) paradigm suggest that the endogenous activation of effect codes (such as for the present prepared response) concurs with a central stage of processing (e.g., Kunde, Pfister, & Janczyk, in press; Paelecke & Kunde, 2007). In contrast, influences of exogenously presented effect stimuli seem to affect processing within the perceptual stage (Paelecke & Kunde, 2007). Accordingly, the present blindness-like effect suggests that it is the perceptual stage of the exogenously triggered detection task that either starts later with an unaltered duration or that starts immediately but is itself prolonged. Such a model, however, also allows for other sources for the observed RT effect that do not rest on the TEC framework (e.g., changes in the duration of the central stage of the detection response). Carefully investigating this issue certainly is a fruitful question for future research.

A second implication of our results concerns the relation of endogenous and exogenous action control systems. Previous behavioral studies showed participants to be impaired when they had to perform a partly prepared action as an immediate response to a sudden stimulus (as compared with a condition without endogenous action preparation; Astor–Jack & Haggard, 2005; Obhi & Haggard, 2004). These response costs are commonly interpreted as reflecting a process of switching from endogenous to exogenous action control (Obhi, Matkovich, & Gilbert, 2009; in addition to general inhibition, cf. Obhi, Matkovich, & Chen, 2009). The present results extend these findings by suggesting that the interference effect might involve perceptual processes as well—resulting from a binding of perceptual codes in endogenous action plans. These codes have to be released to allow for an exogenous response to a corresponding stimulus. Tentatively, it might thus be useful to consider these systems to involve perceptual features in addition to their traditional conceptualization.

In sum, assuming that codes of distal action effects are readily integrated into endogenously planned actions (Pfister et al., 2010), the now occupied code is shielded from other processes—giving rise to the reported blindness-like interference when the very same representation appears as a stimulus prompting an exogenously controlled action. This interference effect has important implications for studies targeting the neurophysiological substrates of both systems which, up to now, mainly reported a difference between endogenous and exogenous actions in motor-related areas (Jahanshahi et al., 1995; Rowe et al., 2010; Wiese et al., 2004). The present results, however, suggest a differential interaction of both systems regarding sensory processes, indicating that the dissociation of endogenous and exogenous action control might be even more fundamental than previously assumed.

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Received July 25, 2011
Revision received November 14, 2011
Accepted November 15, 2011 ■