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The impact of subliminal effect images in voluntary vs. stimulus-driven actions

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ABSTRACT

According to the ideomotor theory, actions are represented in terms of their sensory effects. In the current study we tested whether subliminal effect images influence action control (1) at early and/or late preparatory stages of (2) voluntary actions or stimulus-driven actions (3) with or without Stimulus-Response (S-R) compatibility. In Experiment 1, participants were presented at random with 50% of S-R compatible stimulus-driven action trials and 50% of voluntary action trials. The actions' effects (i.e. up- or down-pointing arrows) were presented subliminally before each action (i.e. a keypress). In voluntary actions, participants selected more often the action congruent with the prime when it was presented at long intervals before the action. Moreover they responded faster in prime-congruent than in prime-incongruent trials when primes were presented at short intervals before the action. In Experiment 2, participants were only presented with stimulus-driven action trials, with or without S-R compatibility. In stimulus-driven action trials with S-R compatibility (e.g., left-pointing arrow signaling a left keypress), subliminal action-effects did not generate any significant effect on RTs or error rates. On the other hand, in stimulus-driven action trials without S-R compatibility (e.g., letter "H" signaling a left keypress), participants were significantly faster in prime-congruent trials when primes were presented at the shortest time interval before the action.

These results suggest that subliminal effect images facilitate voluntary action preparation on an early and a late level. Stimulus-driven action preparation is influenced on a late level only, and only if there is no compatibility between the stimulus and the motor response, that is when the response is not automatically triggered by the common properties existing between the stimulus and the required action.

1. Introduction

The ideomotor theory of action control (Lotze, 1852 and Harless, 1861) is considered to be central to the understanding of human voluntary action. According to the ideomotor theory, an action is represented in terms of its desired sensory effects and actions are selected by internally activating these effect representations (James, 1890; Greenwald, 1970; Prinz, 1990). A large number of studies provide experimental evidence for the ideomotor theory (Hommel, 1996; Elsner & Hommel, 2001; Kunde, 2001; Kunde, Koch, & Hoffmann, 2004; Herwig, Prinz, & Waszak, 2007). For reviews of the issue, see Shin, Proctor, and Capaldi (2010) and Waszak, Cardoso-Leite, & Hughes (2012).

Despite its undisputed importance, the temporal dynamics of action-effect prediction remains unclear. Assuming serial motor action stages, the question is whether action-effect prediction is involved in early motor preparation stages, late motor preparatory stages, or action execution. The question is essential as its answer indicates whether effect anticipation is an integral part of action selection or whether it is mainly used for quality control and error handling, respectively (strong vs. weak version of the ideomotor theory; cf., Ziessler & Nattkemper, 2011).

The few studies that explored this topic previously found conflicting evidence suggesting that action-effect prediction either modulates only later stages of motor preparation (Ziessler & Nattkemper, 2011; Desantis, Roussel, & Waszak, 2014) or that it also modulates early stages, such as action selection (Kunde et al., 2004; Paelecke & Kunde, 2007; Janczyk, Pfister, Hommel, & Kunde, 2014; Wirth, Pfister, Janczyk, & Kunde, 2015) and initiation (Kunde et al., 2004). However, most of these latter studies

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investigated actions where the correct motor response was determined by the stimulus. Thus, it is uncertain whether their results generalize to voluntary actions, the more so as a number of experiments suggest a partial independence of the voluntary and the stimulus-driven action system (Waszak et al., 2005; Herwig et al., 2007; Haggard, 2008; Passingham, Bengtsson, & Lau, 2010; Krieghoff, Waszak, Prinz, & Brass, 2011). Desantis et al. (2014), on the other hand, studied the influence of voluntary action-effect prediction on the perception of the anticipated effect. In this experiment, participants were presented with action-effects that were either congruent or incongruent with effects they previously learnt in an acquisition phase. Crucially, these action effects were displayed at different time points, not only after the action, but also before. Desantis et al. observed that participants showed a higher sensitivity (d′) to the effect in compatible vs. incompatible trials. This was the case when stimuli were presented from about 220 ms before the action to 280 ms after the action. The authors suggested that their experiment indicates a lower bound of the start of effect anticipation, as at earlier stage, the predicted effect could be represented in a format that is not closely related to *perception* and, therefore, does not influence discriminability. It is, thus, unclear whether similar results would be observed if the dependent variable assesses *motor processes*.

We addressed this issue in two experiments using a new protocol that allowed us (1) to investigate both stimulus-driven and voluntary actions by means of the same procedure, (2) to evaluate the impact of effect anticipation in stimulus-driven actions that differ according to the compatibility between the stimulus and the response (S-R compatibility), and finally (3) to assess the influence of this effect anticipation on different stages of action preparation (early vs. late).

Important in the current context, recent studies employing imaging technics showed that brain regions involved in the perception of learnt action-effects are activated when participants perform the action that previously produced the effects, even when these effects were not present anymore (Kühn, Seurinck, Fias, & Waszak, 2010; Kühn, Keizer, Rombouts, & Hommel, 2011). These results are in line with the ideomotor theory in that they suggest that performing an action involves the same representation as perceiving the effect it is associated to (Waszak et al., 2012). Action-effect anticipation, thus, rests on the internal preactivation of representations that are involved in forthcoming perception.

In accordance with this latter idea, Kunde (2004) showed that stimulus-driven actions which were subliminally primed by their acquired effects were faster and more accurate than stimulus-driven actions that were subliminally primed by the effects of the other action. It seems, thus, that not only endogenously but also exogenously induced activation of an effect image triggers or primes the corresponding action (cf. Paelecke & Kunde, 2007; Shin et al., 2010), even when the preactivation is induced by means of subliminal stimuli representing the acquired action-effects.

Note that a protocol using subliminal action-effect primes is an excellent tool to investigate the temporal dynamics of the role of effect images, since it can be used with different action types, and since subliminal primes can be presented at any moment before action execution. Another advantage is that it prevents participants from applying a conscious selection strategy and from showing a behavioral perseveration bias (perceived action effects inducing the same motor pattern again, resulting in motor perseveration; cf. Kunde, 2001).

The current study, therefore, harnesses a subliminal-priming protocol similar to Kunde (2004) to test whether effect representations are involved (1) at early and/or late motor preparatory stages of (2) both stimulus-driven and voluntary actions and (3) whether their impact depends on the stimulus-response (S-R) compatibility in stimulus-driven actions. Both experiments include an acquisition phase creating associations between two actions (i.e., key-presses) and two visual effects (i.e., up- or down-pointing arrows, clearly visible) and a test phase using the previous action effects as subliminal primes which were displayed at different SOAs before the action. As will be detailed in the Methods section, we chose the different SOAs in order to maximize the chance of targeting different action stages based on previous studies (Deecke, Grözinger, & Kornhuber, 1976; Deecke, Weinberg, & Brickett, 1982; Praamstra, Stegeman, Horstink, Brunia, & Cools, 1995; Wolpert, 1997; Dirnberger, Fickel, Lindinger, Lang, & Jahanshahi, 1998; Ziessler & Nattkemper, 2011; Desantis et al., 2014). Moreover, in each experiment we designed two types of trials which were mixed within the blocks of the test phase. In the first experiment, 50% of the test trials were partly-instructed trials where participants were free to execute one or the other action - as fast as possible - after perceiving a particular GO stimulus, whereas the other half of the test trials consisted in fully-instructed trials where participants had to quickly execute a target-determined action. Fully instructed trials are stimulus-driven actions since all the action parameters (i.e., "what" and "when") are determined by the stimulus. Partly instructed trials correspond to what has been called in the literature "intention-based" or "voluntary" actions because participants are free to choose between two actions, the "what" parameter of the action remaining unspecified by the stimulus.

In the second experiment, all the test trials were stimulus-driven. However, 50% of the test trials were S-R compatible (e.g., right-pointing arrow requiring a right key-press) whereas the other half of the test trials were not S-R compatible (e.g., "S" letter requiring a right key-press). Taken together, we, thus, could test whether subliminal sensory effects influence our dependent variables differently according to the action type and to the S-R compatibility.

Based on the notion of serial stages in action control (Deecke et al., 1976, 1982; Wolpert, 1997; Dirnberger et al., 1998; Kunde et al., 2004; Paelecke & Kunde, 2007; Ziessler & Nattkemper, 2011; Desantis et al., 2014; Wirth et al., 2015), we hypothesized that if a representation of the action-effect is induced by the subliminal primes, then we should observe effects on response choices and RTs, respectively, depending on the SOA of the primes. Concerning voluntary action, longer time intervals between primes and actions, overlapping with early motor stages, should show an effect on response choices (i.e., more responses congruent with the prime). Shorter time intervals between primes and actions, overlapping with later motor stages, should show an effect on RTs (i.e., faster responses when primes and actions are congruent). This pattern of results would indicate that effect representations influence both early and late motor preparation stages, in line with the strong version of the Ideomotor principle (James, 1890; Prinz, 1990). Another possibility was, of course, that we only find an influence of the primes presented at short time intervals before the forthcoming actions, on RTs. This would indicate that only later stages are affected.

Concerning stimulus-driven actions, we believe that action-effect anticipation processes differ according to the S-R compatibility of the stimulus-response event (Kornblum, Hasbroucq, & Osman, 1990). A common spatial feature between the visual stimulus (e.g., rightward-pointing arrow) and the motor action (e.g., right keypress) leads to more automatic (Kornblum et al., 1990; Eimer, 1995) and reflex-like actions. This type of action should be minimally mediated by mental representations. In the absence of a common attribute between the visual stimulus and the motor action (e.g., letter stimuli) the stimulus-response translation depends on intermediate cognitive representations of the action, and probably on the anticipation of action-effects. Thus, we predicted that stimulus-driven actions with vs. without S-R