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Dissociating action-effect activation and effect-based response selection☆

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ABSTRACT

Anticipated action effects have been shown to govern action selection and initiation, as described in ideomotor theory, and they have also been demonstrated to determine crosstalk between different tasks in multitasking studies. Such effect-based crosstalk was observed not only in a forward manner (with a first task influencing performance in a following second task) but also in a backward manner (the second task influencing the preceding first task), suggesting that action effect codes can become activated prior to a capacity-limited processing stage often denoted as response selection. The process of effect-based response production, by contrast, has been proposed to be capacity-limited. These observations jointly suggest that effect code activation can occur independently of effect-based response production, though this theoretical implication has not been tested directly at present. We tested this hypothesis by employing a dual-task set-up in which we manipulated the ease of effect-based response production (via response-effect compatibility) in an experimental design that allows for observing forward and backward crosstalk. We observed robust crosstalk effects and response-effect compatibility effects alike, but no interaction between both effects. These results indicate that effect activation can occur in parallel for several tasks, independently of effect-based response production, which is confined to one task at a time.

1. Introduction

Performing multiple tasks at once is difficult for human beings and readily leads to performance impairments. The reason behind such performance decrements is often attributed to a serial processing stage that creates a bottleneck in human information processing that can only be occupied by one operation at a time (Pashler, 1994; Welford, 1952). Previous studies have identified the performance bottleneck as *response selection* (McCann & Johnston, 1992; Pashler & Johnston, 1989). That is: Whereas other processing stages can seemingly be carried out in parallel for different tasks, response selection seems restricted to serial processing of one task after the other.

However, evidence of so-called *backward crosstalk* challenges the concept of strictly serial processing (Hommel, 1998; Lien & Proctor, 2002; Miller, 2006). Crosstalk emerges if two tasks, supposed to be carried out at the same time or in very short succession, share certain features (such as requiring a “left” response). Crosstalk manifests as facilitation or interference effects if these features are (spatially) compatible or incompatible, respectively. That is, participants respond faster when the responses for two tasks are compatible than when they are incompatible (see also Way & Gottsdanker, 1968, for an early demonstration of between-task correspondence effects). Crosstalk can affect both tasks at hand and it is termed *forward*, if the first task affects the performance of the second task, whereas it is termed *backward*, if the second task affects the performance of the first task. The observation of backward crosstalk is especially relevant because strictly serial processing of both tasks would not allow for such backward crosstalk to take place, as relevant response features would only be retrieved during response selection. An adjustment of the bottleneck model therefore assumes an additional stage of *response activation* to take place before response selection, with possible crosstalk between tasks happening during this stage.

Direct evidence for the concept of response activation as a parallel rather than serial process has been observed with response-priming setups (Schubert, Fischer, & Stelzel, 2008). Participants in this study worked on a psychological refractory period (PRP) task that is commonly used to probe for response selection bottlenecks. PRP designs typically consist of two tasks (e.g., McCann & Johnston, 1992; Miller & Reynolds, 2003; Pashler, 1994; Pashler & Johnston, 1989). These tasks either have to be executed at (almost) the same time or with a considerable delay between tasks. The rationale behind this design lies in the assumption that interference due to multi-tasking should occur only

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in situations in which task timing demands for parallel processing of both tasks – a demand which cannot be met in capacity-limited stages (i.e., *response selection*). Such timing demands occur when both tasks are presented at the same time or in very short succession (i.e., with short stimulus onset asynchronies, SOAs). In these instances, performance of at least one of both tasks should take considerably longer than in conditions with less demanding timing, i.e., when participants have ample time to execute either task (or at least to execute the capacity-limited stages) one after the other (long SOA). In order to test the idea of response activation in pre-bottleneck stages, Schubert and colleagues presented a subliminal prime – a masked arrow stimulus – before stimulus onset in the second task. Subliminally presented arrow stimuli have been shown to exert robust priming effects by activating spatially corresponding responses (e.g., Eimer, 1999). If response activation were restricted to bottleneck stages of information processing, no such priming effects would be expected to arise in bottleneck stages. Schubert and colleagues, however, observed robust priming effects, indicating that response activation does indeed occur in pre-bottleneck stages (for corresponding theoretical perspectives, see Lien & Proctor, 2002; Schubert, 2008).[2]

But what exactly are the features that are activated during response activation and that determine compatibility of two actions? Because actions are assumed to be represented in terms of their perceptible effects (ideomotor theory; Greenwald, 1970; Hommel, 2009; Hommel, Müsseler, Aschersleben, & Prinz, 2001), crosstalk might be expected to emerge based on the compatibility of the to-be-produced action effects, and this is precisely what has been reported (Eder, Pfister, Dignath, & Hommel, 2017; Janczyk, Pfister, Hommel, & Kunde, 2014). In other words: performing multiple actions at once is more effective when action effects of both tasks are compatible (cf. also Janczyk, Skirde, Weigelt, & Kunde, 2009).

Studies on effect-based crosstalk typically combined experimental designs that allow for testing bottleneck models – such as the PRP paradigm – with experimental designs that allow for measuring the impact of anticipated action effects – such as the response-effect (R-E) compatibility paradigm. In the R-E compatibility paradigm, the participants' responses produce action effects such as visual or auditory events that are predictably coupled to each motor response. Responses and their effects vary on a shared dimension to allow for compatible and incompatible R-E mappings, such as a right key response leading to an action effect on the right side of a computer screen (compatible) versus on the left side of the screen (incompatible; e.g., Ansorge, 2002; Chen & Proctor, 2013; Janczyk, Yamaguchi, Proctor, & Pfister, 2015; Kunde, 2001; Pfister, Kiesel, & Melcher, 2010; Pfister & Kunde, 2013; for the concept of dimensional overlap, see Kornblum, Hasbroucq, & Osman, 1990). When participants' responses (spatially) match the subsequent action effects, i.e., when response and effect are spatially compatible, they respond faster than when response and effect do not match. That is, although the respective action effects are not present at the time of the participants' response, they affect the participants' actions. Consequently, the impact of R-E compatibility on action production can only be explained in terms of action effect *anticipations*.[3]

As action effects are important for any singular action, it seems reasonable to assume that they may also play a role when two or more actions are performed at the same time. Indeed, recent studies have investigated the role of effect anticipations in multi-tasking, attempting to reconcile this basic principle of action control with the task processing framework outlined in the multi-tasking literature. Current interpretations of the reported evidence localize effect anticipations within the capacity-limited central bottleneck, i.e., the response selection (Kunde, Pfister, & Janczyk, 2012; Paelecke & Kunde, 2007; Wirth, Pfister, Janczyk, & Kunde, 2015).[4] Crosstalk, by contrast, is supposed to take place during response activation, a stage that can still be performed in parallel for multiple tasks (Eder et al., 2017; Hommel, 1998; Janczyk et al., 2014). In other words, theory suggests that during response activation, the expected action effects of two or more actions can be represented and activated at the same time, yielding compatibility influences between different tasks coined as crosstalk, whereas compatibility influences related to a task's response and its effect (also requiring action effect representation) takes place in a separate, capacity-limited step (for possible reasons discussed later). If this is true, crosstalk on the one hand, and R-E compatibility effects on the other hand should arise in separate stages and should therefore be independent from each other (McClelland, 1979; Sternberg, 1969).

At first sight, the localization of crosstalk and R-E compatibility effects in distinct processing stages might be assumed to reflect that crosstalk is based purely on anticipated effects (what could be labelled "E-E correspondence") whereas R-E compatibility involves response and effect alike. This is not the case, however. Rather, the technical notation of "R-E" conceals that response-effect relations describe relations between body-related effects (e.g., a hand moving to the left or right) and an additional external, environment-related effect (e.g., a lever moving to the left or right). However, actions can be represented and addressed by any type of effect – be it a visual event in the agent's surroundings or a proprioceptive change resulting from the moving body –, and agents have considerable flexibility regarding which representation to use (Hommel, 1993; Hommel, 2009; Memelink & Hommel, 2005). Because any action may be represented in terms of body-related effects or also in terms of additional environment-related effects (Pfister, Janczyk, Gressmann, Fournier, & Kunde, 2014; Wirth, Pfister, Brandes, & Kunde, 2016), R-E compatibility effects, too, reflect costs that arise due to different effect representations (see Pfister & Kunde, 2013, for a related discussion). Effect-based crosstalk and R-E compatibility effects are thus based on the same types of representations. What likely differs between both effects, however, is that crosstalk is mainly based on activation of intended, task-relevant effects alone – irrespective of whether these intended effects relate to the body, the environment, or both –, whereas R-E compatibility also draws on additional effects that are not directly relevant to the goal at hand. Because most actions will typically aim at producing effects in the outside world, the dissociation between task-relevant and task-irrelevant effects will at times correspond to a distinction between (certain) environment-related effects and body-related effects. This correspondence is merely coincidental though and not a theoretical necessity. In any case, the notion that backward crosstalk and R-E compatibility both draw on effect codes that represent a certain action opens up the possibility that both processes might interact. However, as outlined above, previous findings in the literature suggest that both processes pertain to independent stages of information processing.

[2] A boundary condition for parallel activation of response codes is that the experimental setup must allow for crosstalk between both tasks, in terms of overlapping stimulus and/or response sets (Schubert et al., 2008; for related evidence, see also Ellenbogen & Meiran, 2011; Koch, 2009). The model of Schubert et al. further includes a resetting mechanism that annuls accumulated response activation during the slack time after a response has been identified for the first task. We will come back to this issue in the discussion.

[3] Note that effect-based theories of human action control do not claim that action selection, planning, and initiation necessarily involve environment-related effects such as visible or audible effects of own movements. Even though environment-related effects may dominate at times (e.g., Mechsner, Kerzel, Knoblich, & Prinz, 2001), action control can also take advantage of body-related action effects such as proprioceptive or kinesthetic effects that are intimately coupled to each movement (Pfister, Janczyk, Gressmann, et al., 2014; Wirth et al., 2016). From an ideomotor perspective, the operational description of "response-effect" compatibility thus actually reflects "effect-effect" compatibility between body-related and environment-related effects as we will describe later in the introduction (Pfister & Kunde, 2013).

[4] We follow the terminology of Hommel (1998) by distinguishing (parallel) response activation from (serial) response selection proper. The latter stage can also be found under the labels of response verification (Kornblum et al., 1990) or response identification (Schubert et al., 2008) in the literature.