Acta Psychologica 160 (2015) 141–151

Contents lists available at ScienceDirect

Acta Psychologica

journal homepage: www.elsevier.com/locate/actpsy

Through the portal: Effect anticipation in the central bottleneck

Robert Wirth [a,*], Roland Pfister [a], Markus Janczyk [b], Wilfried Kunde [a]

[a] *Department of Psychology, Julius Maximilians University of Würzburg, Röntgenring 11, 97070 Würzburg, Germany*
[b] *Department of Psychology, Eberhard Karls University Tübingen, Schleichstraße 4, 72076 Tübingen, Germany*

ARTICLE INFO

Article history:
Received 8 April 2015
Received in revised form 16 July 2015
Accepted 17 July 2015
Available online xxxx

Keywords:
Action control
Ideomotor theory
Action effects
Psychological refractory period
Movement trajectories

ABSTRACT

Ample evidence suggests that motor actions are generated by mentally recollecting their sensory consequences, i.e., via effect anticipations. There is less evidence, though, on the capacity limitations that such effect anticipations suffer from. In the present paper we aim to overcome shortcomings of previous research on this issue by extending the set of empirical indicators of effect anticipations and by using trial-wise instead of block-wise manipulations. In four experiments using the locus of slack- and the effect propagation-logic, we found conclusive evidence for effect anticipation taking place in the capacity-limited central bottleneck. These findings extend previous research suggesting an overlap of a "response selection" process as assumed in traditional stage theory and effect anticipation processes as assumed in effect-based ideomotor models of action control.

1. Introduction

1.1. Sensorimotor and ideomotor approaches

"Why did the chicken cross the road?" The most common answer to this question – "to get to the other side" – highlights the importance of action goals for how (human) agents select particular actions and the corresponding bodily movements. Although there is quite a consensus about this, not all traditions of psychological theorizing assume a function of such goals in the very generation of motor acts, i.e., for the immediate control of bodily movements. In particular, sensorimotor, stimulus-oriented approaches conceptualize motor control mainly in terms of responding to external stimulation and consider goals to be unrelated to the mechanics of generating a motor act (Massaro, 1990; Sanders, 1998). More precisely, these theories often assume a series of exogenously initiated, consecutive stages: Stimuli are encoded in a perceptual stage, which is followed by a central stage that is mainly in charge of response selection, even though the exact mechanisms of response selection are not specified. Finally, a motor stage controls response initiation and execution (e.g., McClelland, 1979; Sanders, 1980; Smith, 1968). By contrast, ideomotor, effect-based models emphasize that actions are selected and initiated endogenously by anticipating the outcome that one intends to achieve (Greenwald, 1970; Hoffmann, 1993; Hommel, Müsseler, Aschersleben, & Prinz, 2001; James, 1890; Lotze, 1852; Prinz, 1987), what in turn activates the suited motor patterns to produce the intended goals.

At first glance, these two approaches appear as mutually exclusive. However, because they focus on different aspects of action control, this is not necessarily true. Whereas ideomotor models provide a mechanism that explains how actions are selected and initiated, sensorimotor models stress the sequence of information processing stages irrespective of the stages' mechanistic features. Importantly, within the framework of sensorimotor models, researchers have developed a sophisticated set of methods to locate any type of process within one of the assumed stages. By combining the parsimonious mechanisms of ideomotor theory with the sensorimotor-based methods, previous studies set out to reconcile the two apparently separate views on action control (Kunde, Pfister, & Janczyk, 2012; Paelecke & Kunde, 2007).

In these studies, participants made speeded responses to a stimulus, and each response predictably triggered an action effect. These action effects shared a common dimension with the response (e.g., left vs. right responses triggering left or right effects on the computer screen). The manipulation of *response–effect* (*R–E*) *compatibility* typically yields slower responses when actions and effects are (spatially) incompatible rather than when they are compatible (Ansorge, 2002; Badets, Koch, & Toussaint, 2013; Chen & Proctor, 2013; Janczyk, Yamaguchi, Proctor, & Pfister, 2015; Keller & Koch, 2006; Kunde, 2001, 2003; Kunde, Müsseler, & Heuer, 2007; Pfister & Kunde, 2013; Pfister, Dolk, Prinz, & Kunde, 2014; Shin & Proctor, 2012; Yamaguchi & Proctor, 2011). As the action effects are not physically present at the response time (RT) measurement, but only appear after the response, it seems reasonable that they were indeed represented prior to movement onset. In other words, the action effects were anticipated.

These studies already used the methods that will be introduced in the next section, and their results suggested the anticipative mechanisms of ideomotor theory to coincide with the central stage of response

---

* Corresponding author.
E-mail address: robert.wirth@uni-wuerzburg.de (R. Wirth).

http://dx.doi.org/10.1016/j.actpsy.2015.07.007
0001-6918/© 2015 Elsevier B.V. All rights reserved.

selection that is proposed by sensorimotor approaches. Yet, these previous studies do not yet allow for a definite answer to the question of whether or not ideomotor effect anticipations might indeed be the mechanistic content of the response selection stage, and the present set of experiments was designed to further corroborate this hypothesis. We will therefore describe the methodological toolbox of sensorimotor approaches in the next section, followed by a summary of two critical open questions that call for empirical clarification.

1.2. Mapping behavioral effects to stages

Determining in which of the three stages of information processing a behavioral phenomenon of interest resides is possible within the framework of the Psychological Refractory Period (PRP) paradigm (e.g., Janczyk, 2013; Janczyk, Augst, & Kunde, 2014; Janczyk, Dambacher, Bieleke, & Gollwitzer, 2015; McCann & Johnston, 1992; Miller & Reynolds, 2003; Pashler, 1984, 1994; Pashler & Johnston, 1989; Ruthruff, Miller, & Lachmann, 1995; Van Selst & Jolicoeur, 1994). In the PRP paradigm, participants perform two independent tasks (Tasks 1 and 2) in close temporal succession, and the imperative stimuli of both tasks appear with a varying stimulus onset asynchrony (SOA). The PRP effect denotes the slowdown of responses to the second stimulus with a short SOA as compared to a long SOA (for comments on exceptions to the PRP effect, see Janczyk, Pfister, Wallmeier, and Kunde (2014)). In the well-known central-bottleneck model, this is explained by assuming the central response-selection stage to be capacity-limited, in the sense that two tasks cannot entertain this stage simultaneously (thus a central "bottleneck"; Pashler, 1994; see Fig. 1), while the other stages can run in parallel with other stages. With a short SOA, the central process of Task 2 therefore is delayed because the bottleneck is still occupied by the central process of Task 1, which ultimately results in longer RTs in Task 2. With a long SOA, both tasks are temporally more separated, and their central processes have little or no overlap. Consequently, responses to the second task are faster at long as compared to short SOAs.

This paradigm also allows for mapping behavioral effects that an experimental manipulation evokes onto one of the information processing stages by means of two experimental approaches: The *locus of slack*-logic and the *effect propagation*-logic. To use the *locus of slack*-logic (Schweickert, 1978), the experimental factor of interest is implemented in Task 2. If then RTs of Task 2 (RT2) are affected at long SOAs, but not at short SOAs, this experimental manipulation appears to affect the perceptual stage (cf. Fig. 1): At long SOAs, the longer perceptual stage of Task 2 directly lengthens RT2, but at short SOAs, the longer perceptual stage is compensated for by stretching into the idle time created by the delay of the central stage (the *cognitive slack*). In statistical terms, this pattern of results is an underadditive interaction of SOA and the factor of interest. If responses to the second task are equally affected at all SOAs (i.e., additive effects of SOA and the factor of interest), the experimental manipulation must affect the central stage or the later motor stage, as lengthening in these stages cannot be compensated for by the cognitive slack.

In this latter case, the *effect propagation*-logic can be used to further differentiate between the motor stage and earlier (central and perceptual) stages. Now, the order of the two tasks is reversed, i.e., the crucial experimental manipulation is implemented in Task 1. If the manipulation affects the central or perceptual stage of Task 1, the beginning of the Task 2 central stage would be postponed and RT2s should be equally lengthened, i.e., the effect of Task 1 propagates to Task 2 (at least at short SOAs with sufficient temporal overlap between the two tasks). In contrast, if the manipulation affects the motor stage (of Task 1), performance in Task 2 should not be influenced at all, because the motor stage runs in parallel with the Task 2 central stage.

To sum up, the following predictions can be derived within the PRP framework for the RTs of Task 2, the former two relating to the *locus of slack*-logic and the latter two relating to the *effect propagation*-logic:

- If the experimental manipulation is implemented in Task 2, an underadditive interaction between the factor of interest and SOA speaks for a locus in the perceptual stage.
- If the experimental manipulation is implemented in Task 2, additive effects of the factor of interest and SOA speak for a locus in the central or motor stage.
- If the experimental manipulation is implemented in Task 1, a propagation of the effect of interest to Task 2 (especially at short SOAs) speaks for a locus in the perceptual or central stage.
- If the experimental manipulation is implemented in Task 1, the absence of a propagation of the effect of interest to Task 2 speaks for a locus in the motor stage.

1.3. The present experiments

The two available studies reported (1) additive effects when using the locus of slack-logic and (2) effect propagation into Task 2 when using the effect propagation-logic (Kunde et al., 2012; Paelecke & Kunde, 2007). Still, even though they thus favor the view of effect anticipations occurring within the central bottleneck, two critical aspects do not yet allow for drawing definite conclusions. A clarification of these aspects is important because there is also reason to assume a non-central locus of ideomotor effect anticipations. For instance, congruency effects between stimuli and upcoming effects (S–E congruency) arguably rely on anticipative processes just as R–E compatibility effects, but S–E congruency combined underadditively with SOA and thus seems to influence the duration of the pre-central stages in certain settings (Paelecke & Kunde, 2007, Exp. 4 & 5). Additionally, anticipated action effects have been shown to affect movement execution (Kunde, 2003; Kunde, Koch, & Hoffmann, 2004; Pfister, Janczyk, Wirth, Dignath, & Kunde, 2014), which would be in line with a post-central motor-related locus.

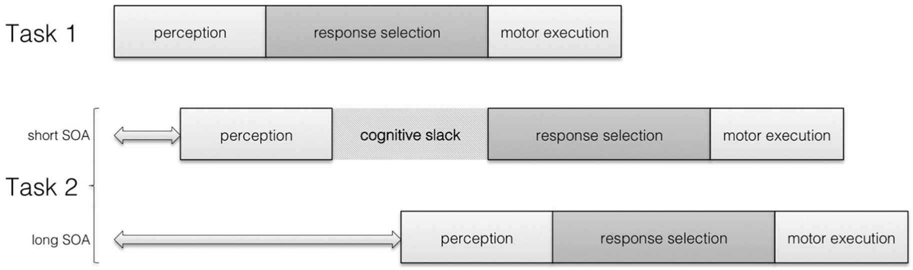

Fig. 1. Illustration of the central bottleneck model (e.g., Pashler, 1994). Because central processes (dark gray) are capacity-limited and cannot overlap in time, in trials with short stimulus onset asynchronies (SOAs, indicated as double arrows), central processing of the second task must wait after its perceptual process has ended. The resulting idle time is called cognitive slack. Responses in the second task therefore take longer with short SOAs compared with long SOAs, and prolonging the perceptual stage of the second task into the cognitive slack does not increase response time in this task.