



Evidence for distinct steps in response preparation from a delayed response paradigm

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ABSTRACT

Task parameters still affect reaction times even when all necessary information for executing an action is presented prior to a Go signal to execute the action. Hypotheses in terms of short-term memory capacity, residual activation, and a separate motor-programming stage have been suggested to explain what can and cannot be prepared prior to a delayed Go signal. To test these hypotheses, we used a delayed response task, in which participants were to initiate a movement at onset of an imperative Go signal following the target stimulus. Across Experiments 1–3 we varied task properties including stimulus type, information uncertainty and response complexity, respectively, while controlling other factors. We also varied the time available to process the response by randomly varying the interval between onset of the target and the Go signal (i.e., the stimulus onset asynchrony, or SOA). If the preparation process is completed before initiation, the examined factor should display a strong interaction with SOA, with its effect disappearing at long SOAs. Our results showed strong, weaker, and no interaction patterns for the three factors, respectively, favoring the separate stage hypothesis, according to which response preparation is separated into steps to arrange kinematic specifications into muscle-controllable terms.

An action requires a series of mental processes prior to physical movement. Completed output from the immediately prior process may serve as input to the next, as in discrete stage models of motor planning (Sanders, 1990; Sternberg, Monsell, Knoll, & Wright, 1978; for recent review, see Verwey, Shea, & Wright, 2015), or the action may be triggered after gradual accumulation of information, as in continuous flow models (Coles, Gratton, Bashore, Eriksen, & Donchin, 1985). In either model type, even a simple movement like a keypress is carried out with advanced motor preparation, defined as “a state of readiness to make a specific planned movement” (Henry & Rogers, 1960, pp. 448–449), which leads to the movement’s ultimate execution. Motor preparation has been studied using precuing methods, in which information relating to target stimulus identity (and the assigned response) is presented prior to onset of the target at varying stimulus onset asynchronies (SOAs). The degree to which the advance information identifies the target stimulus and response can be varied from full to partial to no information at all about the forthcoming stimulus and response. The method has been paired successfully with many measures to examine details of the preparation process: reaction times (RTs; Bock & Eversheim, 2000), event-related potentials (ERPs; Faugeras & Naccache, 2016), functional magnetic resonance imaging (fMRI; Fatima

& McIntosh, 2011), single-cell recording (Wise & Mauritz, 1985), positron emission tomography (PET; Deiber, Ibañez, Sadato, & Hallett, 1996), and eye movements (Huestegge & Adam, 2011).

When the precue completely identifies the upcoming stimulus and response, the task becomes one of simple RT (Forgaard, Maslovat, Carlsen, & Franks, 2011). A simple RT task does not require a choice, since the stimulus and response are known, allowing the response potentially to be pre-programmed. Of particular interest in the present study is comparing the effect of task parameters on fully identified cue conditions, that is, simple RT, to choice RT.

Simple RT is supposed to be independent of response duration (short or long) or complexity (Klapp, 1995), compared to strong interactions with various response parameters found in choice RT tasks (Klapp, 1976). For instance, Klapp, Wyatt, and Lingo (1974) found that pressing a Morse code “dah” took longer than pressing a shorter “dit” in a choice RT task but not in a simple RT task. However, other studies have found a reliable response parameter effect on simple RT (Henry & Rogers, 1960; Khan, Mourton, Buckolz, & Franks, 2008). Comparison of simple RT across conditions can provide a glimpse into what features of the motor planning are completed before action initiation. In Klapp et al.’s study, the decision of whether to make a long or short duration

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keypress was made in advance.

Klapp (1976, 1995) borrowed a traditional memory system analogy to suggest working principles of motor short-term memory (STM) by examining simple RT as a function of response complexity and duration. According to him, motor programming is a process of translation from the highly practiced long-term representation into a muscle controllable short-term code. The motor program cannot be controlled directly from its representation in LTM, requiring generation of an STM code to control responding. In his 1995 study, the number of movement elements (sequences of four presses, e.g., “dit-dah-dah-dit” vs. single-element presses, e.g., “dit”) had more influence on simple RT than did the duration of the single response element (“dit” vs. “dah”). But the difference between one and four elements was small and eventually absent after extensive practice pressing the series of keys over eight days (see also Maslovat, Hodges, Chua, & Franks, 2011). Klapp suggested that preprogramming of the organizing sequence is not possible during simple RT even when information about the specific sequence to be executed is fully provided in advance, due to the limited capacity of STM. But, with practice, participants learn to organize the movement elements into one chunk, which is of loadable size in STM. Thus, Klapp’s STM hypothesis of motor programming suggests that simple RTs should be equal only if the response complexity is the same or a more complex response sequence has been unitized into a single chunk. Participants can take advantage of prior information about the forthcoming movement only when the size of information fits in the memory buffer.

However, Kunde, Koch, and Hoffmann (2004) observed that two fully cued conditions yielded different RTs even after a 1500-ms cue-target interval. In their Experiment 2, participants made a soft or forceful keypress in response to the color of a target stimulus. A fixation cross, which preceded the target stimulus by a randomly varying SOA of 200, 500, 1000, or 1500 ms, was the same color as the target stimulus on two-thirds of the trials (valid precue) and white (neutral cue) on the other third. Participants were to wait until the target stimulus was presented to respond; immediately after the maximum required force was achieved a loud (high intensity) or soft (low intensity) effect tone was presented. The response-effect (R-E) relation was compatible (e.g., soft keypress with soft tone) in one trial block and incompatible (e.g., soft keypress with loud tone) in another. RTs were shorter when the responses were compatible with the produced effect tones than when they were incompatible. This R-E compatibility (REC) effect was smaller in the valid cue condition than in the neutral condition, but the effect was constant across SOAs for both valid and neutral precues. This result is not consistent with the STM motor-preparation model, because the response complexity, which determines whether the response fits in the memory buffer, was the same in both R-E mapping conditions.

Kunde et al. (2004) interpreted the reliable difference between the two fully cued conditions in terms of a residual activation hypothesis. Their account (see Fig. 1) is based on continuous code activation. If motor preparation is a process of continuous response code activation, programming of the code will be constructed in a more specified manner as information is gradually accumulated, with the movements emitted automatically after the accumulated information amount reaches a threshold level. Unless the response is experimentally delayed, the activation is seamlessly continued until the movement is released. But, in a fully cued response paradigm with varied SOAs until a Go signal, some code activation must be postponed until the target stimulus appears. Thus, at initiation, the residual activation is necessary to initiate the action. Kunde et al. stated that initiation involves the same machinery as the earlier part of motor preparation (e.g., selection), with the re-started activation conceived of as completion of the process started during response selection (see the reactivation function to the right side of the vertical line in Fig. 1, which shows correspondence effects being reintroduced when response selection is resumed).

The two hypotheses introduced above provide mechanisms to explain why simple RTs differ even when full information about the to-be-prepared movement is provided. The STM hypothesis (Klapp, 1995)

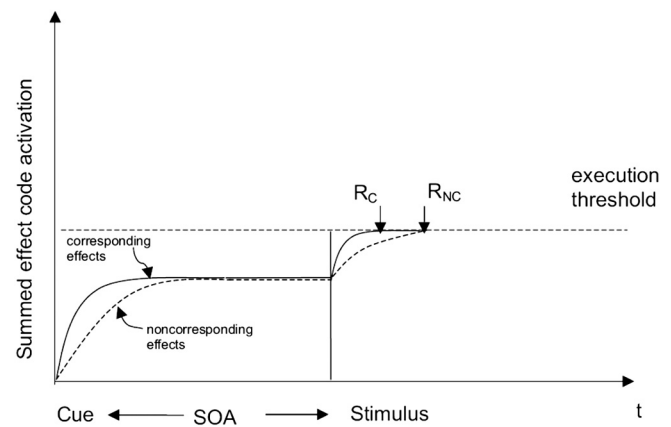


Fig. 1. Hypothetical build-up of effect code activation as a function of preparation time and effect correspondence. From “Anticipated Action Effects Affect the Selection, Initiation, and Execution of Actions,” Kunde et al. (2004), *Quarterly Journal of Experimental Psychology A: Human Experimental Psychology*, 57, p. 102. Reprinted with permission.

explains that a participant “can, but does not have to, take advantage of the advance information” (Klapp, 1976, pp. 723) and will apply the information if its size fits the buffer. The residual activation hypothesis (Kunde et al., 2004) suggests that the residual activation is due to a task-specific delay; without a delay, the response will show continuous activation until it is initiated. According to those authors, motor preparation is “different phases of one and the same dynamic activation of anticipatory effect codes” (p. 95), and “stimulus-induced priming can occur at every point in time before response execution” (p. 102). Thus, a certain property, which mediates selection, may have residual power influencing even initiation.

Shin and Proctor (2012) found evidence that whether the response effect is defined as a goal-satisfying event by instruction, or delivers the information about how the action is executed, influences the RT trend as a function of SOA. When the effect was a goal for a task without information of how the execution was made, the REC effect was found only in the early phase of motor preparation; but when the effect was visual feedback about execution (i.e., a cursor corresponding to mouse movement), the REC effect was found in both early and late phases of preparation. In Shin and Proctor’s tasks, all conditions were the same at the time of stimulus onset; only the information presented after the action was different. The findings of differential time course for anticipating an effect event may reflect the unique status of the late phase of response preparation, which is neither a simple extension nor completion of the prior preparation. We refer to this possibility as the separate stage hypothesis. The description of loading and unpacking of motor program, which is often defined as initiation in discrete stage models, assumes a motor buffer that is controlled by the central processor (Verwey et al., 2015). The separate stage hypothesis suggests that the full loading is possible only immediately before execution; loading cannot be pre-planned even when one knows completely what action is to be performed. Thus, initiation is not reflex-like, as some researchers have suggested (e.g., Hommel, 2000). The delayed response task paradigm reveals this separation.

In the present study, we report three experiments that used a delayed response task similar to that of Shin and Proctor (2012) to test which properties of motor planning cannot be preplanned even with full information about the action to be executed. In a delayed response task, participants are instructed to initiate their responses at the onset of a Go signal, presented after randomly varying delays from onset of the target stimulus, thus reducing certain extra steps required for a cued task. The delayed response task can prevent a strategy often observed in simple RT tasks of withholding the preparation process until the target appears in order to avoid automatic release of the action due to

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