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Action Planning and the Temporal Binding of Response Codes

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The authors hypothesized that action planning leads to the temporal binding of response codes, which then are less available for the planning of other actions. Four experiments showed evidence for this code occupation hypothesis. In Experiment 1, participants prepared a left or right finger movement (A), performed another left–right choice reaction (B), and then executed Action A. In case of a partial feature overlap between A and B, reaction time for B increased. The same was true in Experiment 2, in which B was performed with the left or right foot. Experiment 3 showed that response-feature binding occurred only when there was sufficient time to form a plan. When A was precued but not intentionally prepared, feature overlap produced a decrease in reaction time. Experiment 4 revealed that A benefited from feature overlap with B at short delays but not at longer delays between B and A. This finding was presumably due to leftover activation in feature codes after plan execution, whereas overlap costs in B were unaffected by delay.

Human behavior is not restricted to simple, immediate, and reflexlike responses to environmental stimuli but most of the time is much better characterized as rather complex, intentional, and goal-directed action. In contrast to reflex-driven behavior, voluntary action is guided, and at least partially controlled, by action plans;[1] that is, cognitive structures assuring that intended action outcomes are actually produced in the intended way. In this article, we ask how such action plans look, how they are formed and maintained, and about the consequences of their formation and maintenance. We assume, like others before us, that actions are planned by recruiting codes that represent and control features of the intended action. We further propose, however, that simply activating those codes does not yet make an action plan. Instead, we claim that action plans are created by temporally associating or binding action-feature codes, an assumption that bears obvious resemblance to the object-file concept proposed by Kahneman and Treisman (1984) in the domain of visual perception. In fact, we argue that an action plan may be thought of as an action file that integrates all the information belonging to an action—very much like an object file integrates the information belonging to a perceptual object.

In the following section, we discuss some theoretical considerations and empirical findings that led us to believe that action-feature integration may play a role in action planning. Next, we present the outline of a feature-integration approach to action planning and focus on a particularly interesting implication of this approach: the code occupation hypothesis. We describe how we tested the code occupation hypothesis and report four experiments that provide substantial support. However, we begin with the question of how actions are cognitively represented and the implications of their kind of representation.

Distributed Representation of Action and the Binding Problem

Even seemingly simple actions are complex in several ways. First, they usually consist of multiple components. An elementary action such as grasping an object still requires the coordination of finger, wrist, and arm movements and the spatiotemporal coupling of these movements with the goal object (e.g., Jeannerod, 1981; Marteniuk, Leavitt, MacKenzie, & Athenes, 1990), not to mention the coordination with eye movements or body stance. Second, actions have multiple features, some of which may vary though others should not. Whereas the location of a grasping object indicates the action's invariant endpoint and its form and surface characteristics constrain the way it is to be grasped, the object may be reached at various speeds along one of

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[1] Some authors have drawn a conceptual distinction between *motor programming* and *action planning,* the argument being that planning is necessarily more abstract than programming, covers a longer time span, and has a conscious component (e.g., Jeannerod, 1995; Rosenbaum, 1985). However, we are not aware of any theory of action control that would provide sufficiently specific criteria for a clear-cut a priori distinction between a plan and a program in a given task (see Jeannerod, 1997, for a similar argument). Therefore, and because nothing would follow from making this distinction in the present article, we use the terms *plan* and *program* interchangeably, although with a clear preference for the former (theoretically, a more neutral term).