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The costs of changing an intended action: Movement planning, but not execution, interferes with verbal working memory

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ABSTRACT

How much cognitive effort does it take to change a movement plan? In previous studies, it has been shown that humans plan and represent actions in advance, but it remains unclear whether or not action planning and verbal working memory share cognitive resources. Using a novel experimental paradigm, we combined in two experiments a grasp-to-place task with a verbal working memory task. Participants planned a placing movement toward one of two target positions and subsequently encoded and maintained visually presented letters. Both experiments revealed that re-planning the intended action reduced letter recall performance; execution time, however, was not influenced by action modifications. The results of Experiment 2 suggest that the action's interference with verbal working memory arose during the planning rather than the execution phase of the movement. Together, our results strongly suggest that movement planning and verbal working memory share common cognitive resources.
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A major finding in cognitive psychology is that human thought and action is often guided by a plan, a mental representation that structures complex behavior [18]. There is behavioral and neurophysiological evidence that actions are mentally represented prior to motor execution and that these representations include, for example, the goals and consequences of the action [12]. Action sequences can be planned and covertly represented up to the third movement, before beginning the sequence [8], and it seems that both the beginning and end of a movement are represented in considerable detail [21]. Additionally, activated action representations affect forthcoming behavior. For example, people grasp an object differently depending on the current goal, e.g. fit vs. throw an object [17]. Although prior research provided evidence that actions are planned and represented prior to movement initiation, surprisingly little research has focused on the *re*-planning of actions. How much cognitive effort is required to modify a movement plan? The present study seeks to extend the existing literature by investigating the (dual-task) costs of re-planning an intended action.

Cross-talk between *action* and *cognition* processes has been demonstrated for several cognitive domains, such as perception [11], language [13], emotion [1] and memory [22]. These studies suggest that processes involved in action and cognition tasks share common cognitive resources. Here, we use the term cross-talk in a metaphorical sense; the term is not meant to imply a strictly modular architecture of cognition. Weigelt et al. [25] demonstrated interactions between movement planning and memory processes by combining a motor task (sequential opening of drawers at different heights) with a memory task (letter recall). Weigelt et al. [25] reported two major findings: First, reducing the effort needed for the memory task (i.e. when using free recall instead of serial recall) resulted in stronger movement planning effects, as indicated by the longer persistence of previous action plans. Second, the simultaneous motor task apparently abolished the recency effect, signifying the tendency of recent items to be recalled better than earlier items, which is a well-studied and otherwise stable serial-position effect in working memory research [20]. Logan and Fischman [15] suggest that the abolition of the recency effect is a basic concurrence cost of motor and memory tasks.

Such demonstrations of cross-talk between motor and memory processes raise questions about the locus of the interaction. Does the effort of planning the movement, controlling it during execution, or a combination of both, interfere with the concurrent cognitive process? Glover et al. [7] reported an influence of word labels attached to rectangular target objects on early but not late stages of grasping. Participants showed larger initial grasp apertures after reading words representing relatively large objects (e.g., "APPLE") than after reading words representing smaller objects (e.g., "GRAPE"), suggesting a semantic influence on action

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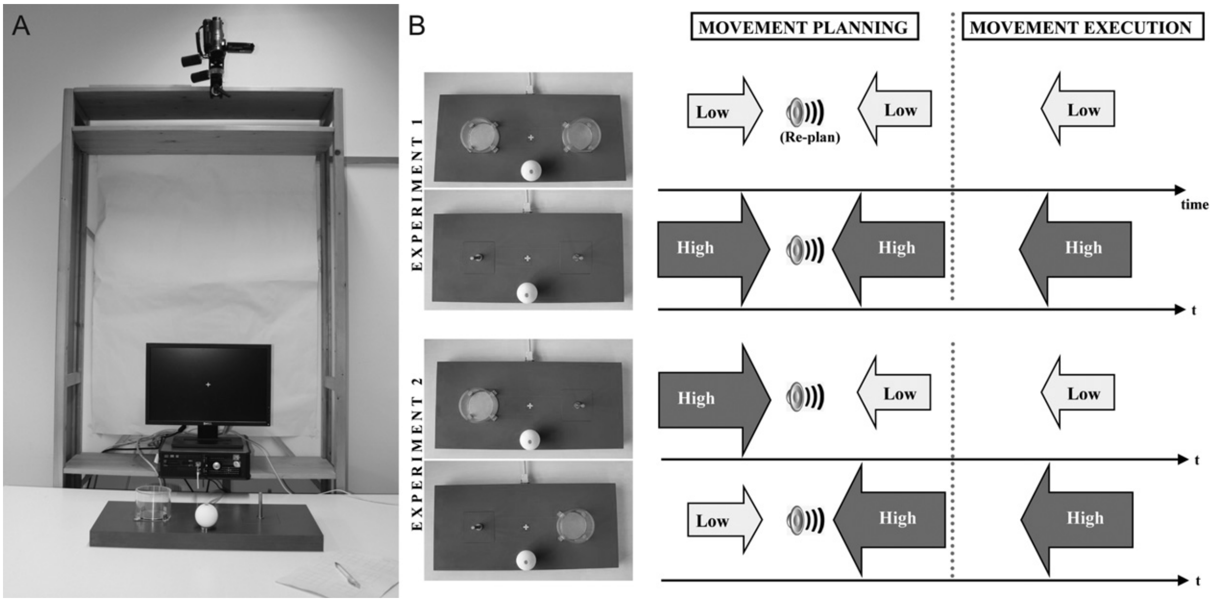

Fig. 1. (A) Full view of the experimental apparatus including task board, PC, monitor, and video camera. (B) Schematic overview of the processing demands in a re-planning trial for both, the planning and the control phase. *Note*. This scheme only depicts trials in which the initial movement was planned to the right target. In the experiment, initial planning direction (left vs. right) was counterbalanced within subjects; *low* = low planning effort/execution demands; *high* = high planning effort/execution demands; *t* = time.

planning. Interestingly, this effect was on-line corrected as the hand approached the target. This continuously decreasing effect is consistent with the view of planning and online-control as being distinct stages of motor actions, as originally suggested by Woodworth [26]. The planning-control distinction assumes that both systems rely on distinct visual representations [6,19], with the planning representations being susceptible to interference from cognitive and perceptual variables, and the control representation being more independent of these interferences [5,7].

Although the ability to re-plan an intended action is crucial in allowing flexible adaptations to changing environments, to our knowledge, no study has systematically assessed the dual-task costs of action modifications. Moreover, it is not known whether dual-task costs are greater for re-planning high versus low accuracy movements. This issue was tested in Experiment 1. In the second Experiment we investigated the locus of motor-memory interactions by assessing whether dual-task costs arise from constraints of the motor system's output during execution, or rather from cognitive effort involved in planning the movement. In both studies, a motor task (unimanual grasp-to-place task) was combined with a memory task (letter recall).

In Experiment 1, we asked whether dual-task costs are greater for re-planning high versus low accuracy movements. Subjects prepared to move the sphere toward one of two identical target positions, which required either low or high accuracy, and subsequently encoded and maintained visually presented letters. Before they executed the placing movement and reported the letters, the planned movement direction was either confirmed or reversed by one of two auditory cues. Hence, two conditions were compared: In the prepared movement condition, participants executed the movement as planned. In the re-planning condition, the participant had to re-plan their movement to the other target position after the presentation of the to-be-memorized letter matrix.

We hypothesized that movement re-planning would require cognitive resources which would interact with verbal working memory. Therefore, we predicted superior memory performance for prepared compared to re-planned movements. It has been shown that high precision movements require increased programming effort because the motor system's output is more constrained due to a larger and/or more precise muscle synergy recruitment pattern [23]. Therefore, we predicted a stronger decrease in memory performance for high compared to low precision placing movements in the re-planning condition. We assume that verbal working memory shares resources mostly with the movement planning phase and should not significantly affect the control phase. Thus, we predicted only a main effect of motor precision for execution time; however, the control phase may well be influenced by motor precision demands.

Forty-eight (24 female, 24 male, *M*age = 25.2 years, *SD* = 3.9, age range: 19–35) right-handed German students with normal or corrected-to-normal vision participated. Participants were compensated with either 5€ or 1 h of participation credits. Subjects were randomly assigned to either the high motor precision group ($N = 24$) or the low motor precision group ($N = 24$).

The task board ($4 \times 60 \times 28$ cm) included a starting position and two interchangeable targets (Fig. 1A). All positions were equipped with pressure-sensitive micro switches in order to record execution times, and to allow self-paced trial beginnings. In Experiment 1, homogeneous motor targets were used: for the high motor precision group, both sides of the task board were equipped with a stick (10 cm high, 0.5 cm wide). For the low motor precision group, both sides of the task board were equipped with a bowl (10 cm high, 10 cm in diameter). The targets were positioned 15 cm horizontally from the centre of the setup, which was marked by a yellow cross. A sphere (6 cm in diameter, furnished with a hole of 10 mm in diameter) either had to be fit onto the stick or put into the bowl, respectively. The left and right directional arrows were of identical size (2.5×1.5 cm). The 3×3 letter matrices (14×10.5 cm) contained nine random consonants of the Latin alphabet (adapted from Sperling [24]). The acoustic stimuli which signalled whether to re-plan or not, were a low and a high sound with the fundamental frequency of 436 Hz and 1280 Hz, respectively.

At the beginning of each trial, the sphere was placed on the starting position. A fixation cross was displayed in the centre of a 17′′monitor with integrated speakers. The self-paced lifting of the sphere triggered the presentation of a fixed sequence of stimulus events (Fig. 2). During a 1000 ms interstimulus interval (ISI), participants moved the sphere above the centre of the setup. Participants

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