Title
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Sequential Movements and the Cognitive Representation of Time

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Introduction

Our cognitive representation of time is not well understood. Models of motor control assume that an actor keeps perfect track of the time that has already elapsed and that will elapse until a target will be reached (e.g., Fitts' law). On the other hand, explicit judgments of time intervals reveal cognitive biases, indicating that our ability to keep track of time is quite limited. This conflict might be due to the artificial nature of explicit time judgments, compared to the implicit timing demands of motor behavior. Three experiments show that motor timing is also prone to cognitive biases, and that time estimation is in turn affected by motor demands.

General Method

Participants alternated with their right hand between two target locations at a prescribed rate. Movements were paced with a metronome that was turned off prior to data collection. Targets were 15 x 15 mm buttons placed approx. 25 cm apart. Two time judgments were obtained: (1) indirect judgments from movement times between targets, and (2) direct reproductions of estimated sequence completion times.

Experiment 1: Anticipation

Eight participants completed 20-second movement sequences with either 24 fast or 12 slow alternations between targets. Targets were also embedded in easy or difficult sequences by including a third, near vs. far element in the alternation tasks. In addition to these dynamic conditions, participants performed 20 seconds of static tapping on single targets with equal pacing instructions, and also retrospectively reproduced their required sequence completion times in static and dynamic tasks.

Movement times between identical targets were faster within more demanding sequences, presumably to allow for longer movement times to more distant subsequent targets. This anticipatory effect does not occur with slow movements. Static tapping was accurate at all locations, indicating that the timing bias was not related to differences in postures (e.g., differential discomfort). Retrospective sequence duration estimates did not discriminate between conditions.

Experiment 2: Uncertainty

To clarify whether time estimates would be more diagnostic for effects of shorter movement sequences, 3 vs. 6 second fast sequences were investigated with 15 participants. To test whether the interpolated motor activity affects the representation of time intervals, reproductions of required sequence completion times were obtained either prospectively or retrospectively.

Replicating the previous finding, there was again anticipation of sequence difficulty in movement times. Overestimation of short and underestimation of long sequence completion times was present for both sequence lengths and with both orders of time judgments. Such range effects typically indicate uncertainty on behalf of the participants.

Experiment 3: Physical and Cognitive Load

Two sequence lengths (3 and 6 seconds), and both prospective and retrospective estimates of sequence durations were used to investigate how a physical load (453g wrist weight) and a cognitive load (120 vs. 27 mm contact area) affected timing and time estimation. 25 students participated.

Physical loading led to faster movements and raised the estimates of total sequence durations. Cognitive loading induced underestimation of sequence durations. Retrospective sequence duration estimates were shorter than prospective estimates for both short and long sequences, indicating that the motor activity itself, rather than memory decay, affected the represented sequence duration.

Discussion

Three studies found effects of movement context and speed requirements on motor timing, as well as effects of physical and cognitive loads on movement time estimation. The assessment of both indirect (movement) and direct (estimation) timing performance suggests a common resource limitation. The widely held view in motor control research of an accurate time-keeper seems mistaken: Cognitive biases similar to those in explicit time estimation occur in the timing of behavior, thus enabling a movement-based approach to understanding the cognitive representation of time.