Temporal Tuning in the Acquisition of Cognitive Skill

Richard A. Carlson (racarlson@psu.edu)
Lisa M. Stevenson (lms152@psu.edu)
Department of Psychology, The Pennsylvania State University
University Park, PA 16802

Fluent cognitive performance depends on concurrent activation of appropriate representations of goals, procedures, and data. This observation is reflected in a number of current theories such as Anderson's ACT-R (Anderson & Lebiere, 1998). Together with the observation that part of the improvement with practice of many skills can be attributed to better coordination of actions with the environment (e.g., Neisser, 1992), this suggests what we call the *temporal tuning hypothesis*: As a consequence of practice, individuals will adjust the timing of their mental and information pickup activities so that the activation of information to be processed is optimally synchronized with ongoing mental activity. Previous research has demonstrated the learning of timing constraints in perceptual-motor (Dominey, 1998) and cognitive tasks (Carlson, Shin, & Wenger, 1994). We examined this hypothesis in three experiments in which participants performed computerized multiple-step arithmetic or spatial tasks.

We examined the possibility of temporal tuning by allowing subjects to control the pacing of their problem-solving performance by pressing keys to briefly display part of the information required for each step. Experiments 1 and 2 used a running arithmetic task in which subjects updated a total at each step. Subjects practiced solving 8-step problems for 10 blocks of 10 trials. In Experiment 1, operators for all steps were visible throughout each trial, and a new operand was displayed in response to a keypress at each step. In Experiment 2, both operator and operand appeared sequentially in response to the keypress. In both cases, the new information was displayed briefly, then masked. We manipulated constraints on timing by varying between subjects the delay between each keypress and the display of the available information. Delays ranged from 200 to 1100 ms. Experiment 3 used a spatial path-construction task with procedures and design similar to Experiment 2, to provide generality across task domains. In all experiments, we changed the timing constraints in final test blocks to verify that the practiced constraints had been learned.

If the structure of mental processes for performing each step allows temporal tuning, with practice subjects should learn to anticipate when they will be ready for the new information and request that information at a time that takes into account the delay. This would result in shorter keypress latencies with longer delays, measured from the onset of the information needed complete a step. Information requests might be initiated on a rhythmic basis, or on the basis of internal or external events that serve as process completion markers. If, on the other hand, participants must wait until a step is completed to instantiate a goal for the following step, keypress latencies will not vary as a function of delay. This might be the case if, for example, problem-solving steps are realized by production rules with inaccessible internal structures.

In all three experiments, we found evidence of temporal tuning: With practice, subjects in conditions with longer delays learned to request information earlier than did those in conditions with shorter delays. When operators for all steps were continuously visible (Experiment 1), temporal tuning was more precise than when the operator for each step was displayed only on request (Experiments 2 and 3). For the arithmetic task, performance was also slower and less accurate when operators appeared step by step. This difference suggests constraints on the ability to anticipate and control the timing of mental activity. One possible constraint is that a goal based on the operator to be applied must be instantiated to initiate a procedure that provides a basis for anticipatory timing.

We consider alternative accounts of how temporal tuning might be accomplished. It appears that typical production-system models of cognitive skill would have to be extended to accommodate the phenomenon of temporal tuning. We consider the implications of this phenomenon for the role of on-line instantiation of goals in theories of cognitive skill.

References

Anderson, J. R., & Lebiere, C. (1998). The atomic components of thought. Mahwah, NJ: Erlbaum.

Carlson, R. A., Shin, J. C., & Wenger, J. L. (1994). Timing and the control of fluent cognitive sequences. Presented at the 35th annual meeting of the Psychonomic Society, St. Louis, November 12, 1994.

Dominey, P. F. (1998). Influences of temporal organization on sequence learning and transfer: Comments on Stadler (1995) and Curran and Keele (1995). Journal of Experimental Psychology: Learning, Memory, and Cognition, 24, 234-248.

Neisser, U. (1992). The development of consciousness and the acquisition of skill. In F. S. Kessel, P. M. Cole, & D. L. Johnson (Eds.), Self and consciousness: Multiple perspectives, (pp. 1-18). Hillsdale, NJ: Erlbaum.