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Adaptation and learning: Characteristic time scales of performance dynamics

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ABSTRACT

A multiple time scales landscape model is presented that reveals structures of performance dynamics that were not resolved in the traditional power law analysis of motor learning. It shows the co-existence of separate processes during and between practice sessions that evolve in two independent dimensions characterized by time scales that differ by about an order of magnitude. Performance along the slow persistent dimension of learning improves often as much and sometimes more during rest (memory consolidation and/or insight generation processes) than during a practice session itself. In contrast, the process characterized by the fast, transient dimension of adaptation reverses direction between practice sessions, thereby significantly degrading performance at the beginning of the next practice session (warm-up decrement). The theoretical model fits qualitatively and quantitatively the data from Snoddy's [Snoddy, G. S. (1926). Learning and stability. *Journal of Applied Psychology, 10*, 1–36] classic learning study of mirror tracing and other averaged and individual data sets, and provides a new account of the processes of change in adaptation and learning.

1. Introduction

The distinction between persistent (learning) and transitory (adaptation) change in performance has a long history in psychology but only sporadic influence in theories of learning (cf. Adams, 1961; Hallett &

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Grafman, 1997; Irion, 1948). This may be because the classic definitions of learning emphasized the "relatively permanent change in behavior" and consequently the strength of long-term memory traces (cf. Hilgard & Bower, 1975). The outcome is that the characteristic time scales of persistent and transitory change in learning have been lost in the contemporary perspective that the power law is the ubiquitous theory of learning (Anderson, Fincham, & Douglass, 1999; Newell & Rosenbloom, 1981).

In this paper, we propose complementary roles for the constructs of adaptation and learning and examine the time scales of their influence to the performance dynamics in sensori-motor skills. We present a two time scale model of adaptation and learning that is derived from a decomposition of the performance dynamics into separate adaptation and learning processes that follow their own characteristic time scales. In this new model of the learning and retention of sensori-motor skills, the processes of adaptation are fast and reversible, whereas the persistent changes of learning are slow and improve performance within and even between practice sessions. The model reflects the co-existence of separate processes during and between practice sessions that evolve in two independent dynamical dimensions characterized by time scales that differ by about an order of magnitude.

The two time scale model of adaptation and learning processes in sensori-motor tasks provides a new set of hypotheses as a distinct alternative to the purely memory-based approach to the processes of change that are offered in current power law models of learning and retention (Anderson et al., 1999; Newell & Rosenbloom, 1981). The dynamic characteristics of the persistent and transient change in motor learning are consonant with recent experimental work in neuroscience on the neural activity in practice and rest associated with learning (Foster & Wilson, 2006; Wixted, 2004).

1.1. Transient change and warm-up

Several sources of transient change in behavior and performance over time have been identified in learning but three distinct types of relatively rapid change are apparent. These are: (1) warm-up decrement – the transient change (improvement) in performance that occurs over the initial trials of a practice session (Adams, 1961; Irion, 1948); (2) the drifting away from previously established performance levels due to fatigue and decrement in attention in the later trials of a practice session (Singer, 1975); and (3) trial to trial fluctuations in outcome that have typically been interpreted as noise-like (Spray & Newell, 1986). Most experimental work on transient change has focused on warm-up decrement with there being considerably less study of the noise-like phenomena and the influence of fatigue in learning. Nevertheless, it is logical to postulate that all three of these classes of transient change bring their own time scales into the performance dynamics of a learning data set.

The original account of warm-up decrement held that the performance loss is a function of losing the contribution of specific task relevant postural and system adjustments that support performance over a rest interval (Adams, 1961; Irion, 1948). Subsequently, Nacson and Schmidt (1971) provided evidence for a more general account of warm-up decrement where the performance loss at the beginning of a practice session or after an extended rest within the same session is due to loss of the general "set" of the participant. The "set" hypothesis holds that the transient decrement in performance following a rest interval is due to the relatively temporary loss of bodily adjustments or states that may include attentional set, arousal level, task relevant attunement of physiological systems, and the rhythm and timing for the trial cycle (Schmidt & Lee, 2005).

The central point of both the specific and general versions of the "set" hypothesis is that the relatively rapid increments of performance observed at the beginning of a practice session are dominated by the adaptive processes of warm-up (Irion, 1948; Nacson & Schmidt, 1971) rather than necessarily the contrasting hypothesis of memory-based processes of forgetting (e.g., Anderson et al., 1999). The determination of distinct characteristic time scales for transient and persistent processes would provide evidence for the non-memory trace view of the adaptive process of warm-up and the independent though combined effects of adaptation and learning processes in performance dynamics.

1.2. Practice schedules, memory consolidation, and time scales

One of the most studied practice phenomena that reflects the distinction between the persistent effects of learning and the transient properties of performance is that of the effects of massed and