Human Movement Science 28 (2009) 319–333

Contents lists available at ScienceDirect

Human Movement Science

journal homepage: www.elsevier.com/locate/humov

Time scales of adaptive behavior and motor learning in the presence of stochastic perturbations

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ARTICLE INFO

Article history:
Available online 4 December 2008

PsycINFO classification:
2330
2343
3720
4160

Keywords:
Time scales
Learning
Stochastic perturbations
Simulated annealing

ABSTRACT

In this paper, the major assumptions of influential approaches to the structure of variability in practice conditions are discussed from the perspective of a generalized evolving attractor landscape model of motor learning. The efficacy of the practice condition effects is considered in relation to the theoretical influence of stochastic perturbations in models of gradient descent learning of multiple dimension landscapes. A model for motor learning is presented combining simulated annealing and stochastic resonance phenomena against the background of different time scales for adaptation and learning processes. The practical consequences of the model's assumptions for the structure of practice conditions are discussed, together with their implications for teaching and coaching.

1. Introduction

In motor learning, we study the various regularities that can be observed when humans (like most animals) show a persistent change in behavioral patterns while trying to reach an explicitly or implicitly defined learning goal. As a consequence of practice, we typically observe an overall steady performance improvement interrupted occasionally by stagnation or sudden dramatic improvements (Bryan & Harter, 1897). It is generally expected that after a considerable amount of practice the performance of the learner comes close to their potential maximum performance level.

To date, motor learning has been assessed primarily by determination of the function for the relatively permanent change of performance: namely, the change in the outcome score of the action over

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0167-9457/$ - see front matter © 2008 Published by Elsevier B.V.
doi:10.1016/j.humov.2008.10.005

practice time. According to the generally accepted view point of Newell and Rosenbloom (1981), the ubiquitous law of learning is a power law (Snoddy, 1926), which by definition has indefinitely many time scales within the range examined. Arising from the power law, several theoretical and practical approaches have been proposed regarding the conditions of practice to optimize motor learning by reducing motor (target) variability and stabilizing movement patterns. Established motor learning approaches to practice conditions include: repetition learning (Gentile, 1972), learning by means of a methodical series of exercises (Gaulhofer & Streicher, 1924), variability of practice (Schmidt, 1975), and contextual interference (Shea & Morgan, 1979).

In this article, we develop the position that the power law of learning and, in consequence, the associated practical development of instructional strategies, contain several assumptions that seem inadequate considering recent theorizing and experimental findings regarding the dynamics of motor learning. These assumptions include: (a) learning goals are subject independent; (b) motor learning goals reduce to a single movement parameter that is typically related to the performance outcome; and (c) the approach to learning goals follows a phenomenologically direct (monotonic) path. Moreover, there are common central elements in the different approaches to the structure of practice conditions in that the goal of a movement learning process consists of: (a) achieving an *ideal* target movement, whose (b) deviations are interpreted as negative interference.

The central theme of the paper is that motor learning is an individual multidimensional construct that is reflected by the time scales of learning and adaptation processes in the presence of stochastic perturbations. Stochastic perturbations are considered to be of special interest because of their presence in different processes of motor control and their potential to relate to several motor learning approaches by means of scaling procedures similar to time scales. Consistent with this framework, empirical, analytical, and phenomenological models are presented, that are based on different assumptions about the role of time scales, motor variability, and individuality during learning and adaptation.

In the first model, a simulation is presented showing the co-existence of growth/decay processes on different time scales and also the redundancy of the learning system – factors that are contrary to the idea of an ideal target movement. This analytical approach is based on artificial neural nets (ANNs) and includes the role of noise during the acquisition phase and its function in promoting learning and transfer. The phenomenological modeling approach to noise includes a class of nonlinear dynamical models with discrete time evolution and both deterministic and stochastic components. Finally, this simulated annealing process is integrated with the processes of stochastic resonance to develop a qualitatively new motor learning approach with different time scales to the processes of learning and adaptation.

1.1. Learning goals are assumed to be subject independent

It seems to be unavoidable by definition to neglect individuality when searching for general laws and principles of human behavior (Chalmers, 1999) though in practice, treatment, training, and other intervention programs, individual behavior has been a secondary focus. In consequence, ideal movement patterns that are derived from general models of the learning process may be inappropriate for some individual performers while in other cases they match very well. Beside the logical problem of trying to become better than the original performance level by movement imitation, the identification of subject specific movement patterns (Schöllhorn, Nigg, Stefanyshyn, & Liu, 2002) challenges this approach to learning. As Schöllhorn and Bauer (1998) have shown by means of pattern recognition procedures, not only individual movement patterns at different performance levels but also differences in gender and nationality can be observed, features that make it very difficult to find a general optimal pattern. In addition, a clear separation of all trials within a single participant (Schöllhorn et al., 2002), of day specificity (Bauer & Schöllhorn, 1997), of fatigue processes according to exhaustive exercises (Jäger, Alichmann, & Schöllhorn, 2003), and of emotional states (Janssen et al., 2008) in several movement patterns has provided further evidence for Bernstein's (1967) insight of practice as "repetition without repetition" or elaborative learning (Shea & Zimny, 1983).

The process-oriented analysis and the inclusion of several variables (Fink, Schöllhorn, & Jaitner, 1999) provides important information about the individual's learning state. These results provide evi-