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Unifying practice schedules in the timescales of motor learning and performance

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ABSTRACT

In this article, we elaborate from a multiple time scales model of motor learning to examine the independent and integrated effects of massed and distributed practice schedules within- and between-sessions on the persistent (learning) and transient (warm-up, fatigue) processes of performance change. The timescales framework reveals the influence of practice distribution on four learning-related processes: the persistent processes of learning and forgetting, and the transient processes of warm-up decrement and fatigue. The superposition of the different processes of practice leads to a unified set of effects for massed and distributed practice within- and between-sessions in learning motor tasks. This analysis of the interaction between the duration of the interval of practice trials or sessions and parameters of the introduced time scale model captures the unified influence of the between trial and session scheduling of practice on learning and performance. It provides a starting point for new theoretically based hypotheses, and the scheduling of practice that minimizes the negative effects of warm-up decrement, fatigue and forgetting while exploiting the positive effects of learning and retention.

1. Introduction

Practice plays an important role in the learning of any skill, but particularly motor skills, as the acquisition of skilled motor performance typically requires several years of sustained practice (Ericsson, Krampe, & Tesch-Romer, 1993). It follows, therefore, that a long line of research in the motor learning domain has been dedicated to the facilitation and optimization of practice in the skill acquisition process. The desire to achieve and maintain a high level of skilled performance in various contexts of life (musical, athletic, etc.) has driven scientists and practitioners to identify the conditions of practice that allow for the attainment of skilled performance in the most efficient manner. Central to this line of investigation has been an understanding of the processes that change task performance over time – regardless of whether that change is between trials of a practice session or the longer duration effects of sessions over days, weeks and years.

Time, and the passing of it, thus plays an important role in motor skill acquisition, as motor skills are generally not learned within one trial or a single practice session. Indeed, the position emerging, that we develop here, is that performance enhancements following practice are the result of change at multiple levels of the system, each with their distinct timescale (Newell, Liu, & Mayer-Kress, 2001). For this reason, the structure and timing of practice strongly influences, if not fundamentally determines, the learning process in a variety of ways. In other words, the strategy with which practice sessions are scheduled and work-rest cycles are distributed influences the level of performance as well as the rate of learning. Thus, we view the formation of the work-rest cycles of practice schedules as a foundational strategy in the learning and optimization of motor skills. Expressed another way, practice

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distribution schedules reflect a principal issue in moving toward a theory of practice, though there are many other instructional strategies that are also implemented and may interact with the distribution of practice to influence the learning process (Davids, Button, & Bennett, 2008).

Generally speaking, the learning literature has distinguished between *massed* and *distributed* practice schedules. In massed practice conditions, individuals are asked to practice a task without rest in between trials and/or sessions. Conversely, distributed practice allows for a between-trial rest period that is longer than the duration of the trial. For between-session designs, and to some extent between-trial designs, there has been no absolute time criterion as to what distinguishes massed from distributed practice (Baddeley & Longman, 1978; Cepeda, Pashler, Vul, Wixted, & Rohrer, 2006; Janiszewski, Noel, & Sawyer, 2003; Lee & Genovese, 1988; Schmidt & Lee, 2011; Son & Simon, 2012). This lack of a clear distinction raises the issue that arbitrarily long intervals in between individual trials could be considered a separate practice session. This opens the question as to at what point does the time between trials become the time between sessions? Moreover, the effects of within-session trial distribution have largely been considered independently of the effects of between-session practice distribution – a relation that we seek to integrate here through a unifying analysis of the respective time scales of change of learning-related processes.

1.1. Timescales of change

Commonly, analyses of performance changes over time, without specific consideration of practice design, are built around a single function of learning that is held to be characteristic for the task at hand (Newell & Rosenbloom, 1981). In fact, the majority of the literature in motor learning has emphasized tasks in which the participant, through only a single practice session, had to rescale an already learned pattern of coordination (Newell, 1985). This approach is limiting given that the data used for function fitting procedures are typically restricted to that of a single process at the task output level. The movement outcome data points are, however, the product of multiple processes at different levels of analysis of the system, all with a particular and distinct effect on the task output. The many quantitative analyses of learning generally do not consider the different constraints that influence the outcome (Newell, 1986) as they are typically averaged across trials and individuals, eliminating the trial-to-trial fluctuations and with that the characteristic dynamics of the system that influence the learning process.

Traditional and contemporary theories in motor learning have focused on the relatively permanent changes in movement capacity as a function of practice (Bower & Hilgard, 1981; Bryan & Harter, 1897; Crossman, 1959; Mazur & Hastie, 1978). And, although it is these persistent changes in performance dynamics that by definition reflect the construct of learning, there are several growth/decay processes that operate on a shorter time-scale, inducing trial-to-trial variations that are often masked or averaged out. Thus, a successful quantitative model should reflect the distinct timescales of the qualitative changes during motor learning, ranging, for example, from neural activity to loss of attention and muscle fatigue. The single learning functions of the power law (Newell & Rosenbloom, 1981) and the exponential (Heathcote, Brown, & Mewhort, 2000) are sufficient to study the general regularities at the level of the task outcome over short time spans, but have not accounted for the continuous and discontinuous changes at the level of the dynamics of the individual over the lifespan (Newell & Liu, 2014).

1.2. An integrated framework

In this article we review and synthesize the findings on the effects of practice distribution schedules on motor learning and performance, and interpret them within a multiple process time scale model of motor learning (Newell et al., 2001). More specifically, the focus is on the fundamental processes engaged both during and between practice sessions, and their influence on performance levels and skill acquisition over time. Although this paper will emphasize findings from the motor learning domain, a considerable segment of the relevant research has come from the context of declarative knowledge learning, and has supported the position that the effects of practice distribution may be general irrespective of learning domain and context (Cepeda et al., 2009, 2006; Donovan & Radosevich, 1999; Son & Simon, 2012).

In many areas of perceptual-motor learning and performance, such as rehabilitation (Newell & Verhoeven, 2016), the principles of motor learning, and more specifically, the organization of practice schedules, are not applied to optimize the time spent (Sawers, Hahn, Kelly, Czerniecki, & Kartin, 2012). Indeed, rehabilitation research almost exclusively focuses on which tasks to practice and at what intensities (Donachy et al., 2004; Kegel, Burgess, Starr, & Daly, 1981). It is specifically in these situations where there is limited practice time available and thus a strong need for positive and sustained effects of practice that implementation of more optimal practice schedules should be guided by the principles of motor (re-)learning.

Similar problems have been observed in educational settings, where schedules of teaching practices have not seen many changes in spite of advancements in the understanding the process of learning (Son & Simon, 2012). In music learning, the principle of distributing practice has guided research studies (Duke, Allen, Cash, & Simmons, 2009; Simmons, 2011), and provided evidence for the positive effects of practice distribution discussed here with focus on motor skill learning. A common basis for the interval between musical practice sessions is rest to counter mental and physical fatigue, although more recent studies of practice distribution in music learning have incorporated neurobiological accounts of memory (Simmons, 2011). The problem of practice schedules in music learning is particularly interesting as it involves a more complex motor skill that requires multiple sessions over an extensive time period of years to master the organization of the multiple degrees of freedom of the system.