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On the optimal degree of fluctuations in practice for motor learning

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ABSTRACT

In human movement science, it is widely accepted that random practice generally enhances complex motor-skill learning compared to repetitive practice. In two experiments, a particular variability-related concept is put to empirical test, namely the concept of *differencial learning* (DL), which assumes (i) that learners should not be distracted from task-space exploration by corrections, and (ii) that learning is facilitated by large inter-trial fluctuations. In both experiments, the advantage of DL over repetitive learning was not statistically significant. Moreover, learning was more pronounced when participants either received corrections in addition to DL (Exp. 1) or practiced in an order in which differences between consecutive trials were relatively small (Exp. 2). These findings suggest that the positive DL effects reported in literature cannot be attributed to the reduction of feedback or to the increase of inter-trial fluctuations. These results are discussed in the light of the *structural-learning* approach and the *two-state model* of motor learning in which structure-related learning effects are distinguished from the capability to adapt to current changes.

1. Introduction

After the empirical evidence obtained in the wake of Schmidt's (1975) *schema theory* and *variability-of-practice hypothesis*, it seems to be widely accepted in human movement science that variable practice generally enhances complex motor-skill learning compared to constant, repetitive practice (for an early critical review, see van Rossum, 1990). In retrospect, however, it was only some years later that the schema-theoretical implication of restricting variability to the limits defined by the features of "generalized motor programs" could be overcome. In this regard, Shea and Morgan (1979) were able to show that practicing arm-movement patterns with different sequencing in a random order outperforms a training protocol where the same patterns are exercised in a blocked fashion. As both groups received exactly the same amount of practice and differed only in the sequential arrangement of the trials, it could be further inferred from this study that the advantage of variable practice cannot be solely attributed to rule abstraction from the overall gathered motor experience. Instead, the structure of the practice session and, in particular, the inter-trial variance also seemed to matter. Referring to the *contextual-interference* (CI) hypothesis, which was originally formulated by Battig (1972) for verbal learning, Shea and Morgan (1979, p. 179) related the revealed superiority of random practice to the idea that "contextual interference is closely associated with ... changes across trials in the experimental and processing contexts" and that "practice under increased

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contextual interference can produce more elaborate and distinctive processing of the material to be learned and thus facilitate delayed retention" (for a critical review of the CI effect in motor learning, see Brady, 1998).

More recently, an alternative explanation for the advantage of random over constant or blocked practice has been proposed in terms of *differencial learning* (DL). This approach was introduced by Schöllhorn (1999), who labelled this form of learning "differencial" instead of "differential" in full awareness of the spelling 'error' in order to stress the approach-specific importance of differen-c-es: "The label 'differencial' particularly emphasises the differences which are produced by two consecutive movements" (Schöllhorn, Beckmann, Janssen, & Michelbrink, 2009, p. 38). As it is assumed that "in all established training approaches, learning seems to be induced by the differences between two consecutive trials and less by identical movement parts" (Hegen & Schöllhorn, 2012, p. 32), it is expected "that an additional intensification of the fluctuations ... enhances performance" (Schöllhorn, 2005, p. 129). "Through a permanent process of creating differences between two consecutive movement executions, the always present noise in the movement is amplified in order to explore the potential task space and to automatically interpolate within these boundaries" (Schöllhorn, Sechelmann, Trockel, & Westers, 2004, p. 13). "Hence, the point is to increase the proportion which deviates from the preceding exercise in order to enhance learning" (Hegen & Schöllhorn, 2012, p. 33).[1]

On a theoretical level, Schöllhorn et al. (2006, p. 16) link the DL concept to the *stochastic-resonance* phenomenon (Ward, Neiman, & Moss, 2002), since "stochastic resonance might benefit training when two noisy signals interact in resonance, with one noisy signal equating to the continuously changing exercises or instructions and the other noisy signal formed by the noisy, dynamic condition of each athlete (e.g. during movement repetitions). ... [Hence,] by confronting [for instance] a footballer with a higher number of practice activities, the probability increases that any of the training exercises can get in resonance with the athlete's needs."

Empirically, the DL approach has been tested in experiments in which "a 'traditional' group practiced the skills under task constraints that contained little inter-trial variability, while another 'differential training' group practiced the skills with variability added to the target skill in the form of random, additional and irrelevant movement components" (Schöllhorn et al., 2006, p. 6). On the basis of such an experimental design, Schöllhorn et al. (2004), among others, obtained superior goal-shot precision, while Beckmann and Schöllhorn (2006) found superior shot put performance in post- and retention tests as a consequence of a differencial-learning intervention (see also Schöllhorn et al., 2006, or Savelsbergh, Kamper, Rabius, de Koning, & Schöllhorn, 2010).

Hence, one ends up with two alternative explanations of the same phenomenon: the CI approach focusing on the elaborateness of the abstracted representation and the DL approach focusing on the exploitation of stochastic resonance. At this point, regarding the design of a decisive empirical test, it has to be recognized that an advantage of variable over constant, random over blocked as well as differencial over traditional practice would be compatible with both accounts. Consequently, the problem arises that an increase of contextual interference is necessarily accompanied by an increase of exploitable inter-trial fluctuations and vice versa. Hence, it seems hard to empirically test both explanatory concepts against each other.

In trying to distinguish the two approaches in the context of motor learning, Schöllhorn et al. (2006) pointed at the fact that "alternating practice of two or more movements at the same time [in CI learning] only covers a small plane in a high dimensional task solution space, while the addition of randomized variability [in DL] covers a much wider area of the high dimensional task solution space" (p. 18). Thus, it can be inferred that, from a DL standpoint, a reduction of the degree of inter-trial variance that was assumed as optimal in classical DL experiments should deteriorate motor learning. As illustrated in Fig. 1, the empirical effects of such a reduction could be investigated by comparing a differencial-learning (DL) group with a structural-learning (SL) group on the one hand and, for control purposes, with a traditional-learning (TL) group on the other hand. Whereas DL participants would experience the whole task space with substantial fluctuations between trials, SL participants would practice exactly the same variants but with a minimization of inter-trial variance. As it can be assumed that, due to the structured order of the variants, the SL protocol still – or even better – allows for the abstraction of an elaborate representation of the task space, no learning disadvantage for the SL compared with the DL group should be predicted from a CI perspective. Hence, one ends up with an experimental between-group design that can claim to count as a decisive experiment. In the present study, this design was pursued in Experiment 2.

Before putting this comparison to empirical test, however, it seems useful to conduct a preliminary experiment to assess the role of augmented feedback in the context of DL. As sketched above, the DL protocol emanates from the idea that the participants should find their individual task-space optima by themselves as a result of the experimentally induced fluctuations. For this reason, participants are typically not given corrective feedback based on some allegedly ideal or optimal technique. In contrast, augmented feedback, which forms a crucial part of most standard practice programs, is typically given in the TL group. Consequently, in reference to the *guidance hypothesis* proposed by Schmidt (1991) and the benefits of reduced feedback frequency found by Winstein and Schmidt (1990), the reported superiority of the DL group might also be explained

[1] In this paragraph, the following citations have been translated from German to English by the authors: "Der Begriff des 'differenziellen' betont dabei insbesondere die Differenzen, die durch zwei aufeinander folgende Bewegungen erzeugt werden" (Schöllhorn et al., 2009, p. 38). "Danach scheint bei allen bekannten Trainingsansätzen das Lernen anhand der Differenzen zweier aufeinander folgender Bewegungen stattzufinden und weniger anhand der identischen Bewegungsanteile" (Hegen & Schöllhorn, 2012, p. 32). "...dass eine zusätzliche Verstärkung der ... Fluktuationen eine leistungssteigernde Wirkung besitzt" (Schöllhorn, 2005, p. 129). "Durch das ständige Erzeugen von Differenzen zwischen zwei aufeinander folgenden Bewegungsausführungen wird das stets vorhandene Rauschen in der Bewegung verstärkt, um den möglichen Lösungsraum abzutasten und innerhalb dieser Grenzen automatisch zu interpolieren" (Schöllhorn et al., 2004, p. 13). "Es geht somit darum, den von der vorigen Übung abweichenden Anteil zu vergrößern und so den Lernerfolg zu steigern" (Hegen & Schöllhorn, 2012, p. 33).

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