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Extensive practice in motor learning: an overview and future directions

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ABBREVIATIONS

LT	Limb and target location
T	Target location only
LT-200	Limb and target location - Moderate practice (200 trials)
LT-2000	Limb and target location - Extensive practice (2000 trials)
T-200	Target location only - Moderate practice (200 trials)
LT-2000	Target location only - Extensive practice (2000 trials)

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ABSTRACT
Extensive practice is observed when performance reaches a plateau despite practice continuation. Although extensive practice promotes better results in retention tests, its status regarding transfer tests is not clear. The Adaptive Process Approach states that transfer will benefit from extensive practice. In turn, the Specificity of Practice Hypothesis states that transfer may be harmed after extensive practice. Each perspective has been around for 30 years, accumulating enough information to support its claims. However, they have not been directly contrasted, and each perspective has independently developed its methodological strategy to understand the role of extensive practice in motor learning. Therefore, it is possible that results supporting the perspectives are by-products of their methodological strategies, providing narrow validation limits to both perspectives. In order to better understand the effects of extensive practice on transfer, it is necessary to contrast the Adaptive Process Approach with the Specificity of Practice Hypothesis in a single and unifying methodological framework.

KEYWORDS: Extensive practice | Adaptive Process approach | Specificity of Practice | Hypothesis | Transfer

INTRODUCTION

Practice is essential for motor learning. In the beginning, both performance error and variability are high. After a period of practice, errors decrease to levels that allow one to consistently achieve the task goal, leading to performance stabilization. Performance stabilization is characterized by either a small variability in performance or an asymptote curve indicating that a plateau has been reached. Extensive practice refers to the continuation of practice after performance stabilization, and it has been shown that extensive practice affects how one responds to new task demands [1]. On the one hand, studies conducted in the scope of the Adaptive Process Approach have found that extensive practice may facilitate transfer. The Adaptive Process Approach predicts that changes in the organization of a skill promoted by extensive practice yield flexibility to handle new situations [2,3]. On the other hand, studies conducted in the scope of the Specificity of Practice Hypothesis have found that extensive practice impairs transfer [4,5].

We believe that the discrepancy in the results between the Adaptive Process Approach and the Specificity of Practice Hypothesis offers an opportunity for theoretical advances. Platt [6] proposed the method of *strong inference*, which emphasizes the need of focusing on the exclusion of a hypothesis as an important step to foster scientific growth. More specifically, contrasting predictions in a way that at least one of them may be excluded as a reasonable explanation of a phenomenon of interest is an important step in

any scientific inquiry [6]. The lack of methods for the exclusion of hypotheses in studies of motor learning has been highlighted elsewhere [7]. The present article aims to offer an argument about how adopting a strong inference stance may advance our understanding of the effects of extensive practice on motor learning.

This paper is organized as follows: we first review studies on extensive practice in the scope of the Adaptive Process Approach. Then, we review studies on extensive practice in the scope of the Specificity of Practice Hypothesis. Finally, in the last section, we suggest a methodological way of contrasting the two perspectives in a single experiment to gain more insights into the role of extensive practice in motor learning.

THE ADAPTIVE PROCESS APPROACH

The importance of the organization of structures of control for learning has been highlighted by the proponents of the Adaptive Process Approach [2,3]. It is suggested that an action program controls a motor skill. An important assumption in the Adaptive Process Approach about how an action program controls a motor skill is that human beings are open systems hierarchically organized [8]; consequently, an action program should also be hierarchically organized in macro- and microstructures [9].

The macrostructure is responsible for the components' sequence and organization, such as relative timing and relative force [10]. In this sense, the macrostructure controls the important aspects for movement patterns or consistency in motor behavior, which is a consequence of components' organization based on the individual's intention [9,10]. It is important because behavior consistency allows for reaching the goals with reliability.

The microstructure is responsible for the movement variability, such as total time and total force. Consequently, the microstructure controls the important aspects for adaptability in motor behavior. Behavior adaptability is necessary since the environment constantly changes, making it impossible to plan all the details in advance. Thus, the microstructure is generated in every trial based on the constraints imposed by the macrostructure [9,10]. Combining a selected macrostructure and a generated microstructure in a single two-level control structure diminishes the central demand for controlling all the motor skills aspects, addressing two of the main motor behavior features, i.e., consistency and adaptability.

The agenda of the Adaptive Process Approach involves the investigation of how the macro- and microstructures of action programs modify when facing different types of perturbations. The general strategy of investigation involves assigning individuals to different groups defined by their amounts of practice or levels of performance stabilization of a given task. Stabilization refers to a state in which an individual has enough practice to consistently reach the goal of a task, named as the performance criterion of the task [11,12]. Of importance, although levels of stabilization are defined concerning results of movement execution, levels of performance stabilization are suggested to reflect levels of organization of systems' internal constraints [12].

Often, investigators are interested in comparing two levels of stabilization: practice until the stabilization of performance (stabilization group) and practice beyond the

stabilization of performance (extensive practice or superstabilization[a] group). In this context, extensive practice refers to the ability to reach the performance criterion repeatedly. Figure 1 simulates the operationalization of the concept of stabilization. Although extensive practice does not promote significant gains in performance, it is expected that extensive practice promotes gains in the capacity to adapt and transfer.

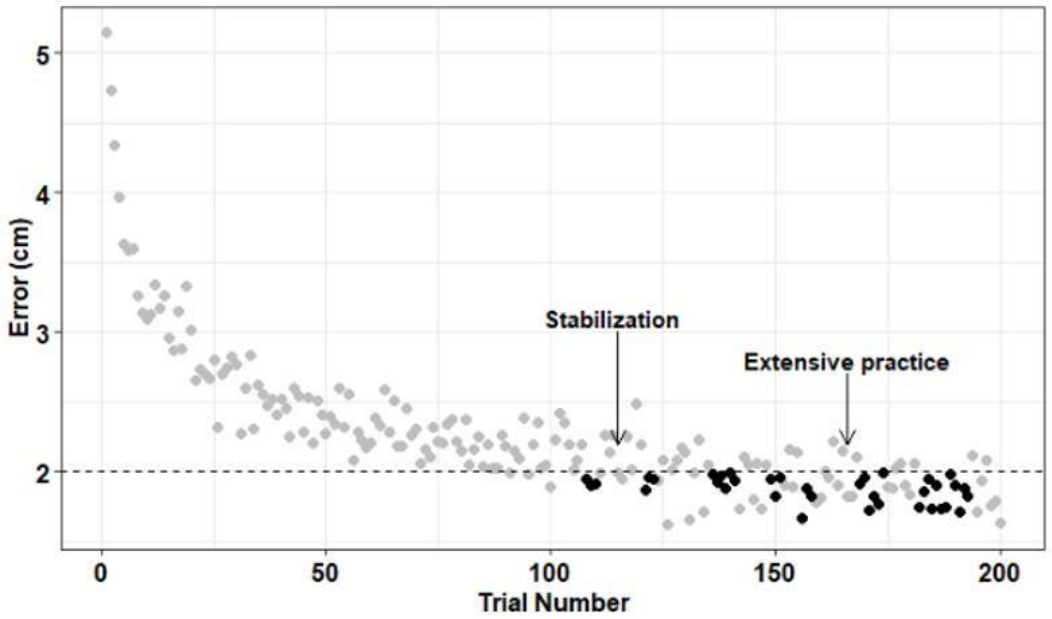

Figure 1. Operationalization of both stabilization and extensive practice in the context of the Adaptive Process Approach. In a hypothetical task, the goal is achieved when the error is smaller or equal to 2.0 cm (dashed line). Stabilization is assumed when the performance is achieved repeatedly under a small bandwidth (e.g., three times in a row, reached in trial number 115), which is named the performance criterion. Extensive practice ends after repeatedly achieving the performance criterion (e.g., six blocks of three trials in a row, reached in trial number 166). The performance criterion is characteristic of each motor task.

There is evidence that extensive practice plays an important role in adapting to both predictable [12] and unpredictable [13] perturbations. For instance, Fonseca et al. [13] compared the adaptation of participants of stabilization and extensive practice groups to unpredictable changes (i.e., perturbations) in a visual stimulus during a timing coincident sequential motor task. Participants of each group were asked to perform a sequential movement pattern touching five components, in which the last component of the sequence was timed to coincide with a moving visual stimulus. In the first phase of the study, the speed of the visual stimulus was predictable, and groups differed regarding their amount of practice. The amount of variability in movement execution and the average result of movement sequences (i.e., error) were similar between groups. In the second phase, the sequence of movement was kept constant, and unpredictable variations in the speed of the visual stimulus were introduced. Results indicated that the extensive practice group adapted better to the perturbation than the stabilization group.

[a] In the Adaptive Process Approach, extensive practice is often referred to as superstabilization. The term superstabilization also encompasses the movement control structure level of organization after an amount of practice that goes beyond what is necessary for an individual to stabilize her/his performance. Since our focus is on the amount of practice, we will stick with the term *extensive practice*.

In general, the extensive practice has led to higher performance variability during practice but better adaptation in tasks with different demands such as timing coincident [12,13], isometric force control [15], and interception of a virtual moving target [11]. Therefore, the effects of the extensive practice should not be ascribed to particularities of task constraints. A possible explanation for the results favoring the extensive practice is that an increase in performance variability after stabilization would represent further exploitation of task solutions, providing the action program with more resources to deal with new situations. Support for that hypothesis more directly was conducted by Ugrinowitsch et al. (2014) [3].

The study design of Ugrinowitsch et al. (2014) [3] was similar to others in the Adaptive Process Approach. In the first phase of the study, three groups were defined based on their stabilization level: pre-stabilization, stabilization, and superstabilization (i.e., extensive practice). As expected, performance variability was higher in the extensive practice group than in the stabilization group. In turn, there was no difference in performance variability between the extensive practice group and the pre-stabilization group. When facing a perturbation in the second phase, the pre-stabilization group maintained low-performance accuracy and high variability. However, the extensive practice group maintained its performance accuracy but diminished variability. The latter was related to modifications in the macrostructure, indicating that variability after performance stabilization was functional, promoting a higher capacity for adaptation.

Overall, the findings of the extensive practice in the Adaptive Process Approach have been interpreted as evidence of the continuity of the motor learning process beyond performance stabilization. It seems that extending practice beyond performance stabilization compared to practice until performance stabilization allows for getting more information related to the task and the environment. However, the role of perceptual information in the control and adaptation of motor skills has not been addressed in the Adaptive Process Approach. This is an issue that has been discussed in the scope of the Specificity of Practice Hypothesis.

THE SPECIFICITY OF PRACTICE HYPOTHESIS

The Specificity of Practice Hypothesis arose to challenge the common statement in the literature on motor learning that individuals become less dependent on environmental information in more advanced stages of learning.16 Notice that similar to the expected effect of the extensive practice predicted in the scope of the Adaptive Process Approach, this idea assumes that learning advances towards the elaboration of an internal representation such as an action program or an internal model, which becomes more sophisticated with practice. Therefore, a better internal representation is seen as relatively protected against environmental influences, and movement would need fewer corrections. The Specificity of Practice Hypothesis states that individuals' dependence on environmental, situational information is higher in the extensive practice.

For instance, Proteau et al. (1987) [5] showed evidence for the increase of performance dependence on environmental information at advanced stages of motor learning. The authors used an aiming task, and the researchers manipulated both the availability of visual sources of information [upper limb and target (LT) vs. target only (T)] and the amount of practice [moderate (200 trials) vs. extensive practice (2000 trials)],

characterizing four experimental conditions, namely: LT-200, LT-2000, T-200, and T- 2000. All four groups were tested in a condition that only the target location could be seen, and knowledge of results was not provided. Proteau et al. found that LT-200 performed better than T-200 during the acquisition phase and the learning test. In turn, participants in LT-2000 performed worse than participants in T-2000 in the learning test, despite their better performance during the acquisition phase. The authors concluded that extensive practice does not get rid of the relevance of environmental information for performance and learning.

Proteau et al. [5] proposed that afferent and efferent information are tailored to become more specific to the learned task as practice extends, which is known as the Specificity of Practice Hypothesis. The key aspect of designing a study to test the Specificity of Practice Hypothesis is the manipulation of information *sources* in non-ballistic tasks. The Specificity of Practice Hypothesis should hold whenever a change in the source of information occurs on which the structure of control of a specific skill relies.

The effect of modifying environmental information is also seen when information is added to a learning test. For instance, Proteau, Marteniuk, and Lévesque (1992) [4] asked participants to perform an aiming task under a perturbation of their arm's trajectory. Participants were assigned to two different conditions regarding the availability of sources of visual information, namely: Limb and target location (LT) or target location only (T). The design consisted of a pretest, an acquisition phase, and post-tests. Post-tests were carried out on conditions like LT but without feedback. Results indicated that the performance of group T decreased more than of group LT in the post-test. That is, making information about the upper limb available to T deteriorated its performance.

The results of the studies described above indicate whether a source of information is removed or added in the transfer test, performance is hindered more after extensive practice than moderate (i.e., until stabilization) practice. Thus, the dependence on environmental information over practice is contextual, and modifying the relation created during the acquisition phase, reinforced more in the extensive practice, seems to disrupt performance. The Specificity of Practice Hypothesis has been tested with different tasks and contexts [17,18]. The theoretical discussion about it has focused on possible explanations for its effects regarding the role of information [13,19]. One important aspect not further explored yet in studies testing the Specificity of Practice Hypothesis is the nature of the control structure that integrates environmental, contextual information to support action.

CONTRASTING PERSPECTIVES AND NEW DIRECTIONS

The Adaptive Process Approach predicts a gain in adaptability promoted by extensive practice compared to an amount of practice necessary to achieve performance stabilization only. In contrast, the Specificity of Practice Hypothesis predicts that extensive practice impairs performance in a new informational context. That is, the Adaptive Process Approach and the Specificity of Practice Hypothesis have in their scope the same object (i.e., extensive practice) but divergent predictions. When facing this apparent contradiction, one may ask: (1) Why do the results diverge? (2) Is it possible to establish a common testing framework to explain these results? (3) Could such a common testing framework

promote theoretical advances in the study of motor learning? In the following, we provide tentative answers to each of these questions.

Why do the results diverge?

Although the Adaptative Process Approach and the Specificity of Practice Hypothesis are interested in the effect of the extensive practice on learning, they present important methodological differences, which may account for the discrepancies in their results. For instance, the criterion to define extensive practice is different. While the number of trials is previously defined in studies testing the Specificity of Practice Hypothesis (e.g., practice ends after 2000 trials), in the Adaptive Process Approach the number of trials depends on subjects achieving a performance criterion (e.g., practice stops after reaching the task goal for six blocks of three trials in a row). Figure 2 summarizes methodological similarities and differences between the Adaptative Process Approach and the Specificity of Practice Hypothesis.

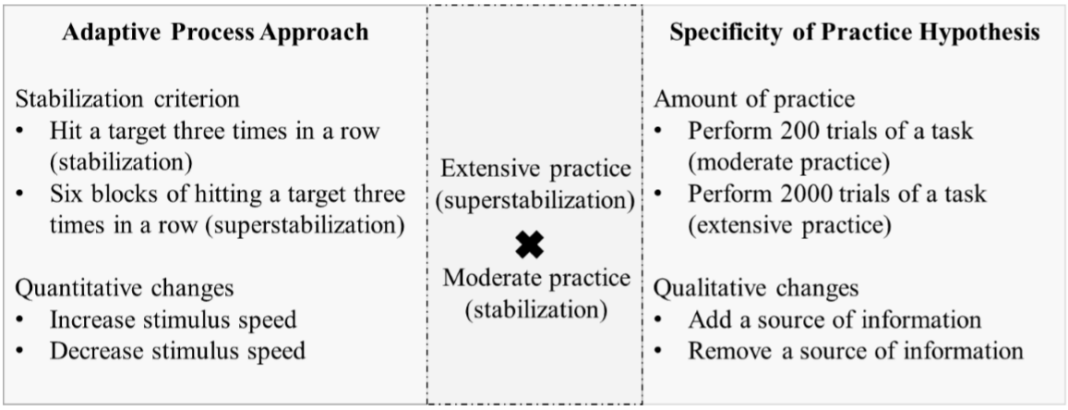

Figure 2. Contrasting methodological aspects of the Adaptive Process Approach and the Specificity of Practice Hypothesis.

In the Adaptative Process Approach, a new testing situation is presented by either changing quantitatively an environmental information [e.g., change in the speed of different portions of a luminous stimulus [13]] or specific motor demands [e.g., the proportion of maximum force [15]]. In both cases, the *sources* of information are maintained in the test. That is, there is not any qualitative change in the test condition. Consequently, adaptation is seen as flexible motor adjustments of a pre-existing control structure (i.e., macro or microstructure of the Action Program Hierarchically Organized) facing similar informational demands. In contrast, in studies testing the Specificity of Practice Hypothesis, the *source* of information is explicitly modified in the transfer test. That is, the change is qualitative rather than quantitative. Since the structure that controls a skill increases its use of information provided by specific sources during extensive practice, any change in the contextual information should harm transfer. Therefore, although the Adaptive Process Approach and the Specificity of Practice Hypothesis share a common interest in understanding how extensive practice affects the motor learning process in general, they have produced results that may be specific to their experimental context.

Is it possible to establish a common testing framework to explain these results?

We have argued that the divergence regarding the extensive practice when one compares the Adaptive Process Approach to the Specificity of Practice Hypothesis is due to the particularities of their methodological strategies tied to their theoretical background. Therefore, a methodological strategy would be necessary to test both predictions simultaneously. We allowed ourselves to perform a mental exercise to propose such a strategy. Essentially, our method must involve a non-ballistic task and contrast extensive practice with a non-extensive practice. Criteria to characterize each type of practice need to be defined beforehand[b]. The relevance of criteria for defining extensive practice has been highlighted [12,20]. Finally, the key feature of the method is that the transfer test should contain both a qualitative change (e.g., removing a source of information such as visual information about the effector) and a quantitative change related to another source of information (e.g., change the speed of a visual stimulus). One may expect that extensive practice will promote worse performance in the scenario of qualitative changes and better performance in the scenario of quantitative changes. Therefore, the experimental design would provide means to reproduce previous results that have been described independently in the literature. The novelty is the interaction between qualitative and quantitative manipulations. How individuals in the regime of extensive practice will respond to that interaction may provide a relevant piece of information for a more generalizable conclusion relative to the role of the extensive practice.

Could such a common testing framework promote theoretical advances in the study of motor learning?

Let us assume that a method like the one we drew above can differentiate between the predictions of the Adaptive Process Approach and the Specificity of Practice Hypothesis as we suggested. Would we be making any theoretical progress? As we pointed out above, a control structure such as an action program advocated in the Adaptive Process Approach does not define the role of contextual, environmental information in its genesis or persistence. In turn, the Specificity of Practice Hypothesis makes claims about the role of the contextual information ignoring the properties of the structure of control that it should integrate. The Adaptive Process Approach and the Specificity of Practice Hypothesis lead to important yet different implications for our understanding of motor control and learning. Contrasting them in a single experiment, we may be able to understand each hypothesis' validation limit. If neither of them holds, then we may come up with a third hypothesis and a new method to test it. This iterative process allows us to build a logical tree that grows by excluding hypotheses,6 promoting a continual exchange between explanatory hypotheses and testing methods that, we believe, will expedite our understanding of the extensive practice.

CONCLUSION

In this paper, we discussed different interpretations of the role of extensive practice in motor learning. The Adaptive Process Approach states that extensive practice

[b] In the Adaptative Process Approach, performance stability and extensive practice have been defined based on performance criteria. In contrast, in the studies testing the Specificity of Practice Hypothesis, the extensive practice has been defined based on the number of trials a participant needs to accomplish. Either criterion may be used as long as it is defined before conducting the main study.

facilitates transfer, while the Specificity of Practice Hypothesis states that extensive practice hinders the transfer of motor skills. These perspectives have been around for 30 years, accumulating enough information to support their predictions. However, they were not directly contrasted yet. We proposed the resolution of the apparent contradiction between the Adaptive Process Approach and the Specificity of Practice Hypothesis can be achieved by applying Platt's methodological strategy of excluding hypotheses. In our opinion, such an iterative process of hypothesis testing may expedite our understanding of the role of extensive practice in motor learning.

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