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Insights on the practice schedule role on performance under a hierarchical system view

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HIGHLIGHTS
- Constant practice affects motor skill's macrostructure.
- Varied practice constrains motor skill's microstructure functioning.
- Hierarchical systems contemplate consistency and adaptability complementarily.
- Motor control structure envolves representation and emergence.

ABBREVIATIONS

C1	Backswing
C2	Forward swing
C3	Post-hitting swing
CO3	Distance of 3.0 m from the target
CO3i	Distance of 3.0 m from the target with a 9º incline on the last meter of the mini-golf putting
CO4	Distance of 4.0 m from the target
D1, D2, D3	Each day of practice
DZ	Distal zone
ES	Effect sizes
EZ	External zone
GMP	Generalized motor program
PZ	Proximal zone
TZ	Target zone
VAR	Performed all trials under these conditions in a counterbalanced order

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BACKGROUND: A theoretical background of hierarchical open systems has emerged as an alternative for explaining consistency and adaptability as complementary in the same motor skill related-structure at different levels of analysis.
AIM: Based on original supporting evidence, this paper presents and discusses how an adoption of such background allows theoretical and methodological insights on the role of practice schedule on performance.
METHOD: Sixteen unexperienced individuals of both sexes performed 240 trials of the golf putting task over three days. They were randomly divided into four experimental groups: CO3 (performed trials at a distance of 3.0 m from the target); CO3i (performed all trials at a distance of 3.0 m from the target with a 9º incline on the last meter of the mini-golf putting); CO4 (performed all trials at a distance of 4.0 m from the target); and, VAR (performed all trials under these conditions in a counterbalanced order).
RESULTS: All groups improved the performances related to the task goal, but in a different way by considering the frequencies of golf putting in different performance zones. Results also showed that the constant groups (CO3, CO3i and CO4) modified the macrostructures in different dimensions over practice, while VAR group only altered the microstructure.
CONCLUSION: The distinct effects of the practice schedules on motor skill structure formation were only inferred because of adopting the hierarchical system view. Based on this background, it was possible to speculate that each practice schedule drives differently the formation of a motor control structure.

KEYWORDS: Macro-micro | Order-disorder | Constraint-emergence | Variability of practice

INTRODUCTION

The practice is an essential aspect for life of human beings. This is because it is *sine qua non* condition for learning of countless motor skills humans perform throughout life to meet their needs (e.g., health, education, work, protection, locomotion, food, leisure and socialization).

One of the most recognized definitions of practice in the field of Motor Behavior is that from Bernstein [1] *"… practice, when properly undertaken, does not consist in repeating* *the means of solution of a motor problem time after time, but in the process of solving this problem again and again …"* (p. 134). One could say that such recognition is based on two main aspects: (1) the consideration of the purposeful and contextual natures of the motor skills. For this reason, the performance is referred to as a motor problem solving. (2) This definition comprises the complexity of events and mechanisms underlying performance from the intention to its result. On this concern, Tani [2] proposes that practice involves a conscious effort of organization, execution, evaluation and modification at each trial.

Over the past fifty years, motor learning studies have sought to understand and explain the effects of the amount and type of variability of practice over trials on performance and learning, as well as their underlying mechanisms and processes. For example, there has been investigation if the variation of motor skill parameters during practice would enrich a cognitive structure named scheme, which would provide the specific values to the central motor command (generalized motor program – GMP) [3]. The main hypothesis here is that the more parameters were varied in the practice, the richer the scheme would be and, consequently, the more accurate would be the values it would provide to the GMP to be run in a new situation [4]. On the other hand, it has been investigated whether varied practice would imply contextual interference on traces, plans or representations which, in turn, would make them more elaborate and organized in the memory, more resistant to forgetting and less dependent on the initial context [5].

There seems to be no doubt about the advances provided by these investigations concerning the understanding of practice scheduling, even as they still represent the state of the art (e.g., [6]). However, they are not without their criticisms, mainly related to their explanatory power regarding consistency and adaptability as essential characteristics of motor skills [7]. For instance, from the schema background point of view, it is clear which memory structures are responsible for both foregoing characteristics (GMP and schema, respectively) and how they can be accessed in terms of measures (relative and absolute spatiotemporal dimensions, respectively). Nevertheless, it is not clear how GMP is formed and transformed as well as how it is selected [8]. Similar problems are seen concerning the background of contextual interference, since how traits or plans would account for the consistency and adaptability of motor skills, as well as being formed and transformed, was also not properly addressed. Finally, when adaptability is addressed, it is only from the parameterization point of view. Despite the importance of this type of adaptation mechanism, it does not allow the understanding of how motor skills are transformed in terms of GMP, traits or plans as part of the continuous process of motor learning [9]. Parameterization refers to those values modifications within the structure of motor skills.

In order to solve these problems, in the last few years practice scheduling has been investigated based on the theoretical background of hierarchical open systems [10,11]. This refers to a metastable multilevel system whose general characteristics essentially invariant, but the behaviour of the components parts is variable [12]. Such a background has emerged as a useful theoretical alternative explaining consistency and adaptability complementarily in the same structure, which implies diminishing in computational overload and eliminating the infinite regression problem [13,14].

In such hierarchical structure, consistency is guaranteed for a macroscopic order, i.e., macrostructure (overall pattern or configuration that emerges from components parts interaction), while microstructure allows the performances to be variable, since they refer to the behavior of the individual components. For instance, the sequential interaction mode from which the volleyball spike emerges is invariant, that is: (1) running, (2) vertical jumping, (3) hitting the ball and (4) landing. Any other way these components interact fails to characterize foregoing motor skill. Nevertheless, with the foot on which side the running is started and finished or the amplitude and number of steps in the running, how high to jump, how to hit the ball and to land emerge from context specificity (e.g., speed of the ball, blockers' displacement, etc.) [10]. As the hierarchical systems are multilevel, both foregoing characteristics can be seen at different scales or levels of analysis. For example, it has been focused from mechanisms underlying the performance of motor skills to observable behaviors. Regarding the first, it has been considered the intention constrains the action programmes macrostructure, while the motor details emerge from peripheral systems. Concerning the latter, one could consider the tactic characterises a team macrostructure, while the players' individual behaviors refer to its microstructure. In addition, differently from the current models and theories, a hierarchical structure conception allows speculating on the changes in the performance in different levels as well as the different ways that adaptation of motor skills takes place (e.g., parameterization/microstructure, structure reorganization or self-organization/macrostructure) [e.g., see [12]].

Since the adoption of an alternative background implies reconsidering the theoretical and methodological *status quo* [15], this paper aimed to present and discuss based on original supporting evidence how the adoption of a hierarchical system conception could contribute to theoretical and methodological insights on the role of practice schedule on performance.

METHODS

Participants

Sixteen volunteers of both sexes (14 men and 2 women), aged between 18 and 27 years (M = 22.0 years; SD = 2.4) participated. The exclusion criteria involved having prior experience on the motor task employed in this study. Participation required the individual's written consent and the experimental protocol was approved by the local Institutional Review Board.

Task and equipment

The task was to perform the golf putting on a mini-golf (an artificial grass surface) 5 m long and 1.5 m wide. The putting target was a hole with 10 cm of diameter located in the center and 40 cm from the end of the mini-golf putting (Figure 1B). In addition to the existing motor learning protocols (e.g. [16]), this task was used because it allowed accessing its hierarchical structure from identification of its interacting components [11], namely: (1) backswing (from the beginning of the movement near the ball up to the highest point reached by the club); (2) forward swing (from the endpoint of the backswing to the contact to on the ball); (3) post-hitting swing (from the impact on the ball to the end of the club movement) (Figure 1A).

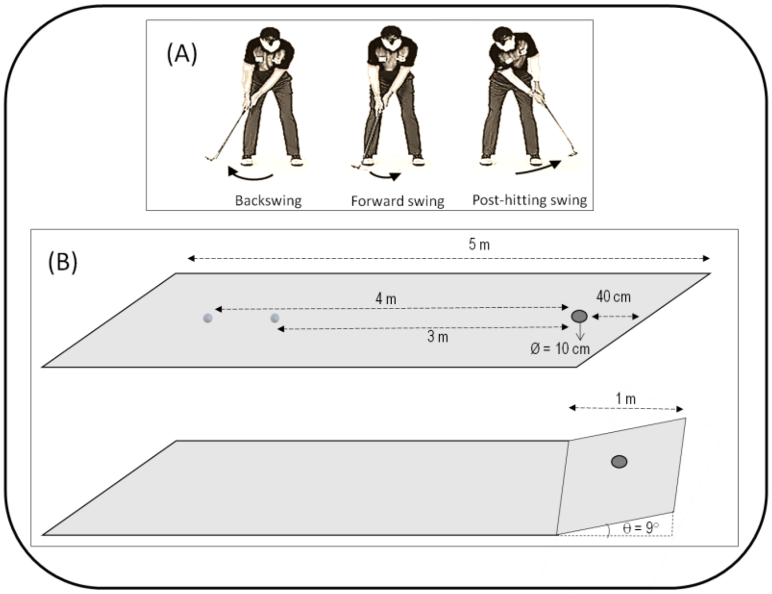

Figure 1. Illustration of golf putting and (A) and artificial grass surface as the mini-golf putting (B).

A putting golf club (TourEdge belly putter 0), which had attached to the top of the clubhead, near the face (impact) side, a bright orange non-reflective styrofoam marker for tracking its displacement, and standard golf balls were used by the participants to complete the task. An IBM-PC compatible notebook with spreadsheet software was utilized for data tabulation and trial number control. A GoPro Hero 3+ camera positioned 2 m away from the participant recorded the trials, with 720p resolution and 120 Hz acquisition frequency.

The Kinovea software (version 0.8.15) was used to extract the bidimensional (planar) spatial coordinates from the video recordings. Calibration was made with a 120x120 cm square frame positioned along the straight line from the initial ball position marker to the target (hole).

Design and procedures

Participants were randomly assigned into three groups of constant practice and one group of varied practice. Three constant groups were considered to avoid that one group practice in a constant way a less functional version of the task. Thus, all kinds of putting were practiced in isolation, that is, without variability of practiced. All groups performed 240 trials over three days, 80 per day. CO3 group performed the golf putting trials at 3.0 m from the target (hole); CO3i group also performed the golf putting trials at 3.0 m from the target. However, there was a 9º incline on the last meter of the mini-golf putting (Figure 1B); CO4 group performed the golf putting trials at 4.0 m from the hole; and, VAR group performed the trials of each day in a random order involving these conditions.

At the beginning of each day, participants watched a video of an expert performing the task. After that, they received instructions about how to perform the task as well as the trials number and intervals between trials. In addition, they were instructed to perform the task with a single motion by moving the club without any preparatory movement [16]. The verbal instructions coupled with the demonstrations contained information about:

positioning of the ball; positioning the feet parallel with the ball in the center; the position of the arms with the left hand holding the upper part of the club with the thumb pointing downwards and the right hand below the left hand, with the thumb also pointing downwards, forming a triangle with the shoulders, arms and wrists; fists should not move; the look should be directed for the ball. Moreover, there was a kinesthetic instruction in which the experimenter held the participant's wrist making it clear that he/she should not move it and that the whole movement (club and arms) should work like a pendulum. All participants could perform three trials before starting the first practice day. They also had visual access to the result of each trial.

Data analyses

From the bidimensional coordinates, the kinematic variables were calculated from raw data in R software environment [17], version 4.0.4, after treatment with a 2nd order, recursive, 10 Hz low-pass Butterworth filter (gsignal package for R). Such variables referred to the space (cm) traveled by the clubhead in each phase/component (backswing, forward swing and post-hitting swing), the time spent by each one (sec), and the relationship between them through dividing the space by time, that is, velocity (cm/sec). From them the measures of macro- and microstructure were calculated.

The *macrostructure* measures referred to the invariant dimensions of golf putting, that is, relative timing, displacement and velocity of the golf putting's components. They were assessed based on the relationship between each component (C1 = backswing; C2 = forward swing; C3 = post-hitting swing) and the golf putting overall pattern. They were calculated through: (i) RtC = (tC ÷ tT) x 100, where RtC was the relative time of the component, tC was the time spent by the component and tT referred to the total time of golf putting; (ii) RdC = (dC ÷ dT) x 100, where RdC was the relative displacement of component, dC was the distance travelled by the component and dT referred to the total clubhead displacement distance; (iii) RvC = (vC ÷ vT) x 100, where RvC was the relative velocity of component, vC was the velocity of component and vT referred to the total clubhead velocity. Macrostructure measures were analysed in relation to magnitude [median (M) of the first 10 trials of the first two days (D1 and D2) and the last 10 trials of the last practice day (D3)] and variability [coefficient of variation (CV) of the same blocks of trials by CV = (σ / M) x 100, where σ referred to the standard deviation of median and M was the median].

Thus, macrostructure comprised: (1) magnitude of relative timing of backswing; (2) magnitude of relative timing of forward swing; (3) magnitude of relative timing of post-hitting swing; (4) variability of relative timing of backswing; (5) variability of relative timing of forward swing; (6) variability of relative timing of post-hitting swing; (7) magnitude of relative displacement of backswing; (8) magnitude of relative displacement of forward swing; (9) magnitude of relative displacement of post-hitting swing; (10) variability of relative displacement of backswing; (11) variability of relative displacement of forward swing; and (12) variability of relative displacement of post-hitting swing; (13) magnitude of relative velocity of backswing; (14) magnitude of relative velocity forward swing; (15) magnitude of velocity of post-hitting swing; (16) variability of relative velocity of backswing; (17) variability of relative velocity forward swing; (18) variability of relative velocity of post-hitting swing.

On the other hand, the *microstructure* measures referred to the overall pattern from the foregoing spatiotemporal measures. They were the total time, total displacement and total velocity. The total time was the time between the beginning of the backswing and the end of the post-hitting swing; the total displacement referred to the distance travelled by the clubhead from the beginning of the backswing and to the end of the post-hitting swing; and, the total velocity was the temporal rate of clubhead displacement from the beginning of the backswing and to the end of the post-hitting swing. These measures were also analysed in terms of foregoing magnitude and variability.

The ball displacement obtained from its bidimensional coordinates allowed accessing the performance related to the task goal. Firstly, it was analysed in terms of radial error (cm). However, it did not prove to be a useful measure to infer changes in performance as a result of practice. It appeared that this has occurred because the level of accuracy (centimeters) was not adequate to the participants' characteristics as novice learners, which tend to make gross mistakes [18]. For this reason, data were analyzed by considering performances zones, similarly to the other studies (e.g., [19]). For this purpose, four zones were considered: (a) target zone – it referred to the hole; as previously described, the hole was located in the center and 40 cm from the end of the mini-golf putting. The circle formed by the radius of 45 cm from the hole center was divided into two zones by forming the (b) proximal zone – circle of 20 cm from the hole border and (c) distal zone - circle of 20 cm from the proximal zone border; (d) external zone - outside 40 cm (e.g., outside the platform). On this concern, performance was analysed based on absolute frequency of occurrence of the golf putting in each zone in the blocks of 10 trials.

Statistical analysis

Since golf putting is purposeful, we first analyzed the performance related to the task goal. This analysis provided a basis for all inferences on the practice effects. For this purpose, the inferential analyses were run using the Trend Module (Multiple Comparisons) of PEPI software [20] for comparing the frequencies of putting of each group in each zone over practice days. By considering the practice nature, it was expected that the further away from the target zone, the greater the frequency of occurrence on the first day, and that this would be reduced with practice, giving rise to an increase in frequency in the target zone. After that, the frequencies of putting in the target zone were compared between groups.

Concerning the macro- and microstructure measures, in order to access how each one behaved over three practice days, a set of Friedman χ^2 tests were run following the Wilcoxon test for the location of differences. These analyses were run using *Statistica® 13.0* software (Stat Soft Inc., Tulsa, USA). For all analyses the level of significance was set at $p < .05$. Finally, the effect sizes (ES) were calculated from the Wilcoxson results through $ES = Z / \sqrt{N}$. Their results were inferred based on the following classification: from 0.00 to 0.10 = null-derisory ES; from 0.11 to 0.29 = weak ES; from 0.30 to 0.49 = moderate ES; above 0.50 = strong ES [21].

RESULTS

Task goal performance

Figure 2 shows the golf putting median frequency of each group in each performance zone over practice. The Trend Analysis and Multiple Comparisons revealed that the constant groups (CO3, CO3i and CO4) had higher frequencies of golf putting in the EZ in D1 than D3; conversely, they had higher frequencies in the TZ in D3 than D1. The VAR group had only higher frequencies of golf putting in the EZ in D1 than D3 (Table 1). In addition, the statistical analyses showed that CO3 had higher frequencies of golf putting in the DZ in D1 than D3; and, lower frequencies in the PZ in D1 than D3. When the groups were compared in D3, differences were revealed only for those in the TZ ($\chi 2$ = 8.74, df = 3, p = 0.03). Statistical analysis showed that the CO groups had similar frequencies of golf putting, and that CO3i had a higher frequency than the VAR group.

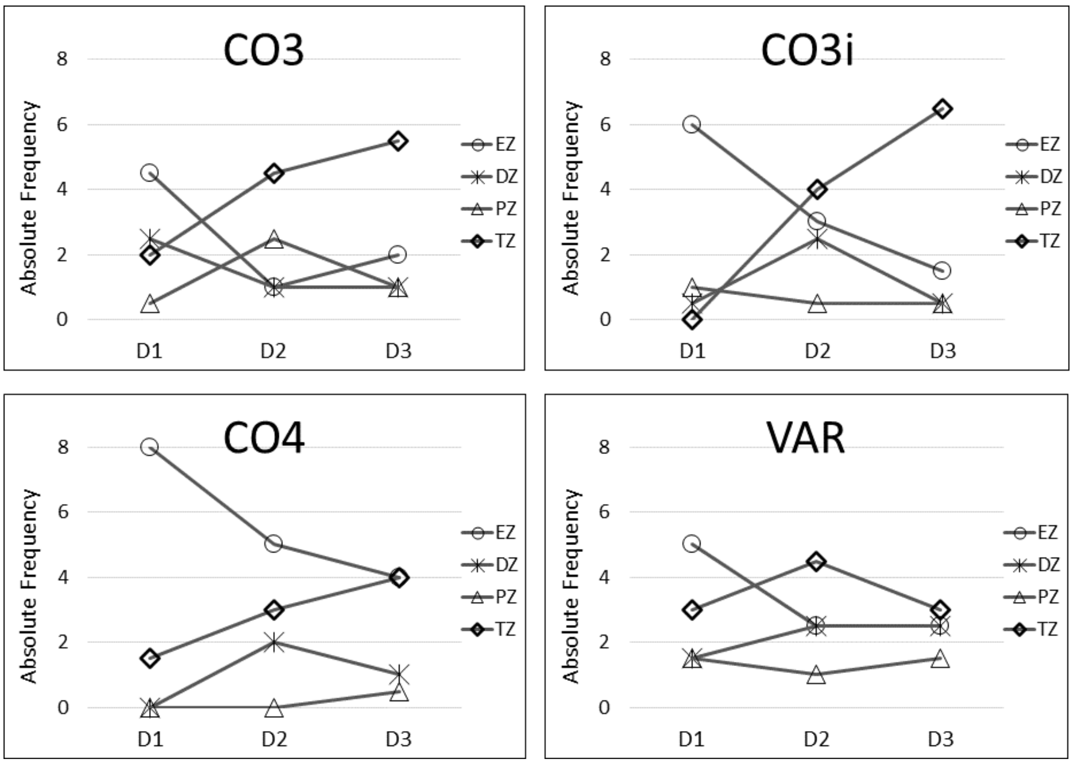

Figure 2. Golf putting median frequency of each group (CO3, CO3i, CO4 and VAR) in the external (EZ), distal (DZ), proximal (PZ) and target (TZ) zones on each day of practice (D1, D2 and D3).

Table 1. Results of Multiple Comparisons for CO3, CO3i, CO4 and VAR groups related to the frequencies of golf putting in the external (EZ), distal (DZ), proximal (PZ) and target (TZ) zones.

Zone	CO3	CO3i	CO4	VAR
EZ	χ^2 = 5.92, df = 2, p = 0.05	χ^2 = 18.00, df = 2, p = 0.00	χ^2 = 11.43, df = 2, p = 0.00	χ^2 = 6.83, df = 2, p = 0.03
DZ	χ^2 = 9.50, df = 2, p = 0.01	χ^2 = 3.50, df = 2, p = 0.17	χ^2 = 7.93, df = 2, p = 0.01	χ^2 = 2.62, df = 2, p = 0.27
PZ	χ^2 = 7.74, df = 2, p = 0.02	χ^2 = 0.60, df = 2, p = 0.74	χ^2 = 2.40, df = 2, p = 0.30	χ^2 = 0.71, df = 2, p = 0.70
TZ	χ^2 = 6.33, df = 2, p = 0.04	χ^2 = 22.57, df = 2, p = 0.00	χ^2 = 9.82, df = 2, p = 0.00	χ^2 = 4.38, df = 2, p = 0.11

Macro- and microstructure measures

Table 2 shows the significant results from Friedman χ^2 tests. The Wilcoxon test pointed out that: (i) CO3 group had relative velocity of backswing in D1 smaller than in D3 and relative velocity of post-hitting swing greater in D1 than in D3; (ii) CO3i group presented differences related to the magnitude of all components in all dimensions, excepting the relative timing of backswing. It had the magnitudes of relative forward swing, displacements of backswing, and forward swing, velocities of backswing and forward swing smaller in D1 than in D3. On the other hand, it had the magnitudes of relative timing of post-hitting swing, displacement of post-hitting swing and velocity of post-hitting swing greater in D1 than in D3; (iii) CO4 had the variability of relative timing of backswing greater in D1 than in D3 and the variability of relative velocity forward swing smaller in D1 than in D3; and (iv) VAR group had the variability of total displacement smaller in D1 than in D3. Importantly, all these days comparisons obtained results varying from moderated to strong ES.

Table 2. Friedman χ^2 tests' significant results.

GROUP	MEASURE	MAGNITUDE
CO3	Magnitude of relative velocity of backswing	χ^2 (N = 4, df = 2) = 6.53, *p* = 0.04
	Magnitude of relative velocity of post-hitting swing	χ^2 (N = 4, df = 2) = 6,53, *p* = 0.03
CO3i	Magnitude of relative timing of forward swing	χ^2 (N = 4, df = 2) = 6,00, *p* = 0.04
	Magnitude of relative timing of post-hitting swing	χ^2 (N = 4, df = 2) = 6,00, *p* = 0.04
	Magnitude of relative displacement of backswing	χ^2 (N = 4, df = 2) = 6,53, *p* = 0.03
	Magnitude of relative displacement of forward swing	χ^2 (N = 4, df = 2) = 6,53, *p* = 0.03
	Magnitude of relative displacement of post-hitting swing	χ^2 (N = 4, df = 2) = 6,53, *p* = 0.03
	Magnitude of relative velocity of backswing	χ^2 (N = 4, df = 2) = 6,50, *p* = 0.03
	Magnitude of relative velocity forward swing	χ^2 (N = 4, df = 2) = 6,50, *p* = 0.03
	Magnitude of relative velocity of post-hitting swing	χ^2 (N = 4, df = 2) = 6,50, *p* = 0.03
CO4	Variability of relative timing of backswing	χ^2 (N = 4, df = 2) = 6,50, *p* = 0.03
	Variability of relative velocity forward swing	χ^2 (N = 4, df = 2) = 6,50, *p* = 0.03
VAR	Variability of total displacement	χ^2 (N = 4, df = 2) = 6,50, *p* = 0.03

DISCUSSION

As in any scientific endeavors, the adoptions of the theoretical and methodological models are influenced by current views (e.g., paradigms). Studies on the practice schedule did not escape this, as they were developed based on one of the most influential motor learning systemic models at the time, that is, the human being as an information processing system. This is the context of both scheme and contextual interference backgrounds, since the way in which the practice schedule affects performance and learning is predicted to be related to cognitive structures involved in information processing.

From a hierarchical system view, the processing involving cognitive structures is also considered, but in a hybrid way. According to Tani [22], at least to some extent of motor skills, the operationalization of the intention would involve the elaboration of an action program as one of their constraints. Such a program would be characterized by control relativity by comprising complementarily constrain (representation) and emergence [23]. For example, the intention would constrain the program's macrostructure as the ways in which its microstructure (components) should interact for giving rise the motor skill. In turn, the components individual behavior would emerge from the environment specificity. To put it in another way, similar to an open system the action program's components interact dynamically, but not to the point of affecting the general configuration of motor skill from trial to trial (consistency). On the other hand, the degrees of freedom that the components have to exert their function allow them to vary according to the context (variability). It is for this reason that the variability of the whole (e.g., macrostructure) would be significantly smaller than the sum of the variabilities of the parts (e.g., microstructure) [24]. Therefore, unlike schema and contextual interference backgrounds, here the cognitive structure would account for both characteristics, consistency and variability, of motor skills.

The first insight refers to the selection of the experimental task (motor skill) and measures appropriate to the phenomenon conception. If micro- and macrostructure refer to the components of a system and how they interact to generate it, respectively, it seems logical that the task should allow a clear identification of both components and interactions. One could say that this is characterized as an important challenge in the Motor Learning subfield. For example, there has been used many artificial tasks, composed by components with no clear function for the whole or difficult to identify (e.g., see pursuit rotor, linear positioning and coincident timing tasks). On the other hand, although numerous real-world tasks (e.g., sportive) have their components clearly identifiable and culturally recognized, the selection of measures that reflect their interactions has not been an easy process, especially when it involves simultaneity and overlap of components functioning (e.g., front crawl swim). On the other hand, for tasks composed by the components interacting in sequential mode like that we used, those recognized measures of invariant and variable spatiotemporal characteristics of motor skills have seemed to be useful for inferring about macro- and microstructure, respectively [23]. For example, while relative timing allows inferences about how the components behave in terms of time proportionally to each other, the overall time reflects the absolute individual time of all components.

And, the second insight refers to how such a hierarchical structure could be considered in explaining the results showing that practice conditions affected the golf putting performance differently. The results allow inferring that all groups improved their performances related to the task goal, but in a different way. While CO3 diminished the frequencies of golf putting in EZ and DZ and increased them in PZ and TZ; CO3i diminished the frequency of golf putting in EZ and increased it in TZ; CO4 diminished the frequencies of golf putting in EZ and DZ and increased them in TZ; and, VAR diminished the frequencies of golf putting in EZ.

It has been predicted that the fact that practice is constant allows the macrostructure formation, that is, it makes possible that the interaction between components to become patterned giving rise to the identity of motor skill [25]. Thus, based on the results one could hypothesize that throughout practice CO3 group modified its macrostructure by increasing relative velocity of the backswing and diminishing it in the post-hitting swing. Interestingly, just the adjustments in the relationship of two components in terms of velocities were enough to make the performance transition through four zones towards the reduction of distance from the goal.

Regarding the CO3i group, it seems that the inclination in mini-golf putting implied more demands on the formation of the macrostructure so that the performance related to the task goal could be improved with practice. This group altered its macrostructure concerning the magnitude of all components in all dimensions, excepting the relative timing of backswing. It diminished the relative timing of forward swing and increased that of post-hitting swing; it diminished the magnitude of backswing and forward swing displacement and increased that of post-hitting swing; it diminished the velocities of the backswing and forward swing and increased that of the post-hitting swing.

It is interesting to note how the change in the performance environment (mini-golf putting) affected differently the performance in the same practice schedule, i.e. constant. For instance, when putting was performed 4 meters away from the hole (CO4 group), constant practice affected the macrostructure formation by fluctuation (alternating diminishing and increasing) of the variability of relative timing of backswing and relative velocity of the forward swing.

In conjunction, these results allow thinking that the focus on macrostructure formation constrained by the constant practice appeared to be an adequate strategy for bettering the performance towards the target attainment. It is important to note that this was not the role of varied practice, as the VAR group modified only its microstructure over practice by diminishing the variability of total displacement. Consequently, its performance relative to target attainment was compromised, since although it increased the frequencies of golf putting in the TZ, it did not decrease them in the other performances zones. Maybe, practice variability functioned as a kind of perturbation on the process of gaining consistency in the interactions between components (macrostructure formation). It is also important to consider that a component is only a component because it interacts with another to form the macrostructure. Thus, it seems reasonable to think that microstructure variability would only become functional by displaying redundancy as interactions become patterned [23]. Thus, it is possible that the constrain influence of the varied practice on performance would be beneficial after macrostructure consistency [25]. Alternatively, the variability of environmental parameters would be logical after the macrostructure has been established.

In general, the distinct effects of the practice schedules on structure formation of motor skill were only inferred because the adoption of the hierarchical system view. Based on this background it was possible to speculate that each practice schedule drives differently to the formation of a motor control structure. Finally, given the speculative nature of this research, its findings need to be investigated experimentally in further studies, including considering a sample size that allows robustness to the conclusions.

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