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Variability and practice load in motor learning
Variabilidad y carga de práctica en el aprendizaje motor

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Abstract

Previous studies have pointed out the convenience of taking the characteristics of the skill to be learned and the intrinsic characteristics of the learners into account when designing practice tasks. Nevertheless, few studies have manipulated the amount of variable practice. The ability to adapt, as an inherent feature of biological systems, can be an adequate framework to explain and predict motor learning processes. This paper is based on adaption processes explained under the theory of allostasis and the general adaption syndrome and shares the background of the Dynamic Systems Theory, to propose the concept of practice load as a useful tool to quantify variability of practice in motor learning. From this standpoint, the conditions of variable practice are reviewed to be a stimulus in an adequate magnitude and direction to take the learner to a higher level of performance and hence to optimize motor learning.

Key words: adaptation; allostasis; training; quantification.

Resumen

Muchos autores han recomendado la conveniencia de ajustar los niveles de práctica variable teniendo en cuenta las características de la tarea y la variabilidad intrínseca que muestra el aprendiz en la ejecución de la habilidad. Sin embargo, no son numerosos los trabajos que han manipulado varios niveles de cantidad de variabilidad al practicar. La capacidad de adaptación, como rasgo de los sistemas biológicos puede resultar un marco adecuado para afrontar esta cuestión. En este trabajo, apoyado en los procesos de adaptación explicados bajo las teorías de alostasis y el síndrome general de adaptación (SGA), y bajo supuestos compartidos por la Teoría General de Sistemas Dinámicos, propondrá el concepto de carga de práctica como una herramienta para cuantificar la práctica en el aprendizaje motor. Bajo esta perspectiva se revisan las condiciones en las que la práctica en variabilidad debe modularse, para suponer una estimulación que facilite al aprendiz una adaptación a un nivel de rendimiento superior y con ello optimizar el aprendizaje motor.

Palabras clave: adaptación; alostasis; entrenamiento; cuantificación.

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Variability and adaptation have been frequently related as both the basis and consequence of each other. Both phenomena are present in our current understanding of evolution since Darwin noted the role of behaviour variability in the emergence of the species as a vital issue for natural selection. In recent years, variability is still an important research topic. Far from being considered an error index of the system, the fluctuations shown by biological systems are considered to be a functional feature of behaviour (Davids, Glazier, Araujo & Bartlett, 2003; Riley & Turvey, 2002), permitting great flexibility in adapting to the environment (Rabinovich & Abarbanel, 1998). From this point of view, it has been suggested that the unavoidable variability of human movement contains relevant information about motor behaviour (Amato, 1992; Newel & Corcos, 1993).

Related to the intrinsic variability of human movement, one of the most studied topics in motor behaviour has been the role of induced variability or variable practice in facilitating motor learning. The formulation of variable practice was originally based on the idea of a generalized motor program in schema theory (Schmidt, 1975). This theory argues that variable practice facilitates the development of rules (schemas) about motor behaviour. Those rules are maintained in memory as relationships between past environmental outcomes produced by the person and the values of the parameters used to produce the outcomes. Therefore, practice has to be designed under varied situations to acquire the most flexible schema, which is able to adapt to a continuously changing environment. From this perspective, most of the studies regarding schema theory have postulated that variable practice is more effective than constant practice in learning skills to be performed in unpredictable environments, or open skills (Lee, Magill & Weeks, 1985; Shapiro & Schmidt, 1982; van Rossum, 1990). In more recent studies, several authors have argued that variable practice is not only useful for learning open skills. Under the Dynamic System Theory (DST), it is proposed that variable practice utilizes fluctuations in motor behaviour to take advantage of individual movement and learning characteristics (Menayo, Moreno, Fuentes, Reina & Damas, 2012; Savelsber, Kamper, Rabius, De Konig & Sholhorn, 2010; Schöllhorn, Beckmann & Davids, 2010). Therefore, the learner is confronted with a variety of movements that span the whole range of possible solutions for a specific task.

Nevertheless, the debate about the utility of variable practice is still present, with some studies postulating greater effectiveness of constant practice under certain conditions (Edwards & Hodges, 2012; Shea, Lai, Wright, Immink & Black, 2001). Ranganathan & Newell (2013), in a review of the characteristics and effects of variable practice, noted that variability may have very different effects on motor learning depending on the task level at which it is introduced and may also be unhelpful under certain circumstances. Excessive induced variability from trial to trial could result in worst results when learning skills under use-dependent mechanisms (Diedrichsen, White, Newman & Lally, 2010) or when a stable coordination pattern is required to perform the task. However, different studies have found positive results when applying variable practice to this type of skills, for example tennis serves (Hernández-Davo, Urbán, Sarabia, Juan-Recio & Moreno, 2014) or hurdling (Schöllhorn, Beckmann, Janssen & Drepper, 2010).

The controversy surrounding the results obtained from the numerous studies about variable practice encourages exploration of the causes of the differences. The study of the characteristics and amount of variability introduced during practice may further understanding of how practice is affected differentially depending on the task to be learned and the intrinsic characteristics of the learner. Some studies have investigated the effects of different parameters of variable practice, for example the information available to the learner (Tremblay, Welsh, & Elliott, 2001), the variability of the task goal or the redundancy of the execution (Ranganathan & Newell, 2010). In recent years, such perspectives as differential learning have proposed to simultaneously vary multiple parameters of movement during practice, showing improvements in motor performance after this method of practice (Reynoso, Sabido, Reina & Moreno, 2013; Savelsbergh, et al., 2010). Regarding the effect of the amount of variability during practice, some studies have noted that higher levels of variability have produced poorer results in learning compared with low values of variability (Caballero, Luis & Sabido, 2012, Ranganathan & Newell, 2010). In a recent study, intermediate levels of variability showed the best results in learning a throwing skill, compared with higher and lower levels of practice variability (Moreno, Peláez, Urban & Reina, 2011). Despite the convenience of taking the characteristics of the skill to be learned and the intrinsic characteristics of the learners into account when designing practice tasks (Davids et al., 2003), few studies have manipulated the amount of variable practice. Therefore, it seems relevant to study not only the characteristics of the variability in practice tasks but also the appropriate magnitude of induced variability in practice situations to optimize the learning process.

From our perspective, the ability to adapt, as an inherent feature of biological systems, can be an adequate framework to explain and predict motor learning processes (Moreno & Ordoño 2009). This work is based on adaption processes explained under the theory of allostasis and the general adaption syndrome and shares the background of the Dynamic Systems Theory (DST). The aim is to propose the concept of practice load as a useful tool to quantify variability of practice in motor learning. From this standpoint, the conditions of variable practice are reviewed to be a stimulus in an adequate magnitude and direction to take the learner to a higher level of performance and hence to optimize motor learning.

Allostasis, adaption and motor learning

Adaption is a complex, global concept, very important to understanding human features and their relationship with the environment (e.g., human evolution, resistance to illness, social transformations or human response to sports training).A 2009 editorial in Lancet brought to discussion the work of Georges Canguilhen in his 1943 book, *The Normal and the Pathological*, rejecting the idea of normal or abnormal states of health. Neither the “state of physical, mental and social well-being”, adopted by WHO in 1946, nor the outdated “the absence of disease,” but the *ability to adapt* is claimed by Canguilhem as the real sign of health. Research about adaption processes has been frequently based on the classics concepts of homeostasis (Cannon 1932) and the general adaptation syndrome (Selye 1956)

All biological systems tend to maintain a complex dynamic equilibrium, or homeostasis. This equilibrium is continuously challenged by internal or external constraints traditionally termed stressors (Braun, Aertsen, Wolpert & Mehring, 2009; Cusumano & Cesari, 2006). Stress is defined as a state in which homeostasis is threatened. The magnitude and characteristics of the stressor stimuli are important. When a stressor exceeds a particular threshold, the equilibrium is altered and a compensatory repertoire of behavioural and physiological responses emerges in the system. The system then restores homeostatic equilibrium after an adaptive response according to the characteristics of the stressor.

Stability through change is an essential and inherent feature of all neurobiological systems in nature. This feature of organisms has evolved to protect them against stress stimuli challenging their equilibrium state. These standpoints have been more recently developed under the theory of allostasis (Sterling & Eyer, 1988), considered a major revision (McEwen, 2000) or a replacement (Sterling, 2004) of the classical theory of homeostasis. Allostasis is proposed as an adequate framework for converging biomedical and psychological models of the stress syndrome, suggesting that the brain acts as the central mediator between the stressor and the adaptive response of the system (Ganzel, Morris, & Wethington, 2010).

Under this perspective, exposure to the stressor and adaptive response are related in an inverted U-shaped curve (McEwen, 2002). Intermediate levels of stimuli permit healthy levels of homeostasis, and very low or excessive levels of stressor exposure leads to negative outcomes. Chrousos (2009) noted three potential situations or effects of exposure to a stressor: First, if the stressor level is close to the centre, the optimal range of the curve and basal homeostasis, a state known as "eustasis," is achieved. In the second situation, termed allostasis or, possibly more appropriately, "cacostasis", the stimuli on both side of the curve lead to insufficient adaption, which might be harmful for the organism, as it is related to a decreased ability to adapt. In a third situation, the intensity of the stimulus matches the characteristics and potentials of the organism, and the organism gains from the experience and a new improved homeostatic capacity is obtained. For this third situation, Chrousos proposed the term "hyperstasis."

One of the relevant contributions of allostasis theory is the concept of cost of adaptation of allostatic load (McEwen & Stellar 1993). In the terms of McEwen (1998) the allostatic load is "*the wear and tear on the body and brain resulting from chronic overactivity or inactivity of physiological systems that are normally involved in adaptation to environmental challenge" (p. 37)*. This way, adjusting the level of the stimuli (or load) to achieve a hyperstatic state is considered the best adaptation with the lowest cost and the best way to improve functionality of the system. The concept of stress load, in relation to homeostasis and adaptation, was first used with its current meaning and popularized bay Selye (1956) through the General Adaptation Syndrome (GAS).

Selye described the GAS as a syndrome in which an organism goes through a specific set of responses and adaptations after being exposed to an external stressor. GAS predicts that when an organism is exposed to an adverse event, the immediate response will be a decrease its functionality, which is termed the alarm stage. If the stress continues, compensation mechanisms will emerge to return to homeostasis and reduce the effect of the stressor, resulting in the adaptation or resistance stage. If the stress intensity is too high or continues for a long time, the system resistance will be gradually reduced, leading to the exhaustion stage, which results in system damages (Figure 1a).

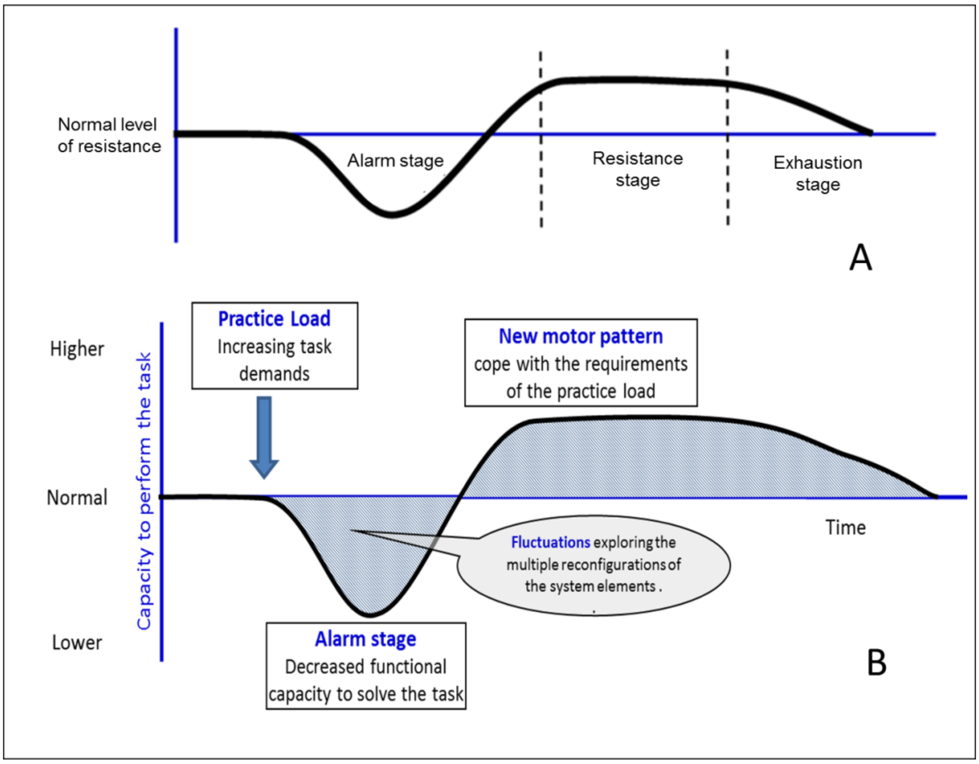

Figure 1 General Adaptation Syndrome representation in which an organism goes through a specific set of responses and adaptations after being exposed to an external stressor (A) and applied to motor learning (B), where the stressor stimuli (practice load) are represented by the tasks proposed by the teacher to provoke changes and adaptation in the learner.

Although GAS came from an endocrinological experiment, it has been applied as a nonspecific phenomenon. Garhammer (1979) applied Selye's GAS to explain physical training and conditioning processes. Indeed, GAS is today a major framework used to study how training loads permit improvements in athletes' physical performance through adaptation processes (Hoffman 2012). Moreover, we consider that the concept of stress load and GAS can be useful tools for facilitating the understanding of other adaptation phenomena such as motor learning, and they share common principles with Dynamic System Theory (DST) (Moreno & Ordoño 2009).

Bringing the principles of GAS to motor learning, the stressor stimuli are represented by the tasks proposed by the teacher to provoke changes and adaptation in the learner. Hereafter, we will refer to those stressor stimuli as *practice load.* If the tasks proposed to the learner are designed as an appropriate practice load with enough magnitude, fluctuations in his behaviour and a decrease in his functional capacity to solve the task will be observed, and the learner will enter the "alarm stage". This alarm stage has also been proposed as an adaptation stage. Fluctuations and temporary losses in stability have been identified when a phase transition from one coordination pattern to another is about to occur (Kelso, 1995). From a DST perspective, we can characterize the skill acquisition process as that of a learner searching for functional states of coordination. Practitioners should understand that a lower performance level of the learner during the acquisition process might represent transient adaptations to the task constraints imposed during practice (Seifert Button & Davids, 2013). The learner will show exploratory behaviours, exploring the multiple reconfigurations of the system elements and allowing possible solutions to the task constraints to emerge from the repertoire of coordinative patterns in the perceptual-motor landscape of the performer (Davids, Button & Bennet, 2008). This stage can be identified as the resistance stage. In the constant "struggle" between intrinsic characteristics of the learner and external constraints, coordination will increase the frequency of appearance, thereby increasing stability and permitting the learner to cope with the requirements of the practice load (Figure 1b). The new stable motor configurations or new coordination patterns showed by the learner will increase the repertoire of attractors to perform skills more effectively.

In an example of this process, a practitioner can propose to modify the running pattern of a learner by asking him to elevate his knees while running. With this aim, the conditions of practice can be modified by adding little hurdles on the floor forcing the learner to modify his running coordination by increasing the upward movement of his legs. While performing the task under these conditions (practice load) the functional ability of the learner to coordinate the movement will be reduced, as he will need to raise his knees over the obstacles, thereby slowing him down (alarm stage). During practice load application, fluctuations and instabilities in the motor coordination pattern will be observed in the search for the optimal solution to cope with the task constraints. After repeated exposure to the practice load, the learner will adapt to this new situation and increase his performance (resistance stage). Thus, when the learner runs in the absence of the obstacles, he will show a new modified coordination pattern. The new stable movement has emerged, conducted by the task constraints during practice and resulting in more elevated knee movements during running.

Newell, Liu & Mayer-Kress (2001) and Liu, Mayer-Kress & Newell (2006) indicated that learning can be understood as adapting to changing constraints across different timescales. So, the alarm and resistance stage provoked by practice load during learning might be reflected not only during the session but also in a more global perspective or in multiple timescales. While changing a coordination pattern during learning, a decrease in performance will be observed on a longer time scale as long as the new pattern of movement affects the stability of the previously preferred pattern. For example, if one tennis player tries to modify his tennis serve technique, the coach can suggest exercises to alter the technique. It is very likely that the previous pattern will decrease in stability as the stability of the new pattern increases. Thus, the tennis player will be immersed in a transient lower performance stage that can last for days or weeks depending on multiple variables such as the magnitude of the practice load or the characteristics of the technique change. Subsequently, the new pattern will acquire greater stability than the previous motion pattern, becoming a new stronger attractor (Davids et al. 2008). If the new attractor is a more effective pattern and better adjusted to subject characteristics, then it can be concluded that the practice load was modulated in the proper direction, and the stability of the new pattern should be related to increased performance.

According to the previous approach, practice should be designed so that the practice load reaches a level neither too low nor too high, but is adjusted for the potential capabilities of the learner to facilitate adaptation (hyperstasis). On the other hand, practice should lead to changes in optimal movement patterns by taking into account the task goals and the characteristics of the learner. The practice load would therefore be defined by the magnitude and direction of its effect, acquiring vector properties. These properties of magnitude and direction are multidimensional and therefore can be defined in a theoretical space.

Practice load estimation and task design for skill acquisition

The quantification of the practice load must take into account the previously mentioned inverted-U relationship between the response of the organism and the intensity of the stressor stimulus (Ganzel et al., 2010). Very weak stimulus levels do not initiate adaptation processes and may even be harmful to the organism. In a more generic example, a muscle that is not regularly activated by the appropriate exercise at moderate intensities may lose volume, increasing fat percentage (Hughes, Frontera, Roubenoff, Evans & Singh, 2002), and decreasing functionality affecting the stability of joints (Dilani Mendis, Hides, Wilson, Grimaldi, Belavý, Stanton, Felsenberg, Rittweger & Richardson, 2009).

Insufficient motor practice would cause few changes in learning and may even cause a decrease in the stability of the motor pattern for the benefit of the stability of other patterns. On the contrary, excessively high practice loads would cause multiple alarm stages, increasing the risk of damages in the short, medium or long term. In the field of motor learning, very high practice loads (situations of excessively high difficulty) could lead the learner to refuse the tasks proposed by the teacher, and it can also cause unwanted adaptations and emerging alternative coordination patterns. These alterations also must be understood in a multidimensional way, being a possible cause of malfunctions in the body (e.g., cardiovascular failure), tissue damage or, more specific to motor learning, alterations in movement coordination patterns (Moreno & Ordoño 2009). From a psychosocial perspective, we could find disruptive behaviours in students or a definitive cessation of activity in athletes caused by repeated high demanding practice loads (Figure 2).

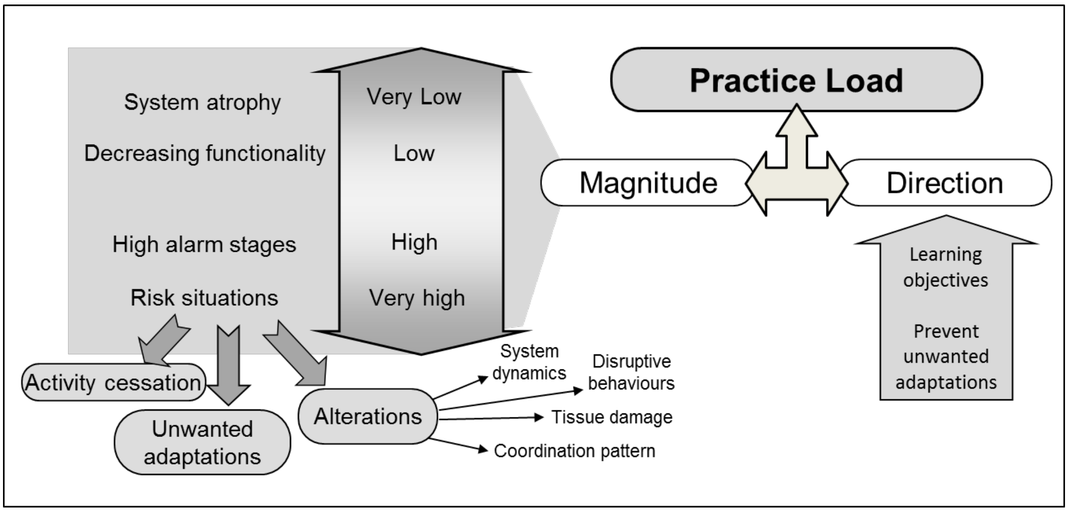

Figure 2: The practice load would be defined by the magnitude and direction of its effect, acquiring vector properties. The effects of the practice load must be understood in a multidimensional way.

With regard to the direction of practice load effects, different load characteristics involve different adaptations. The load proposed by the practitioner can be properly applied in magnitude, for example the amount of weight that an athlete has to move in an exercise to strengthen a muscle group. Nevertheless, if the movement to be performed by the athlete is not adequate to work the desired muscles, different adaptations will emerge in unplanned musculature. We can find these directional effects on the mechanical, metabolic, coordinative or psychosocial level. In fact, the direction of the adaptation is a major issue to the prescription of healthy physical activity. The combination of magnitude and direction will determine the practice load vector in the learning process and, therefore, it is important to assess if the task design is adequate or inadequate for the intended purpose.

We must not forget that the estimated practice load vector will be modulated by multiple elements depending on the context and characteristics of the learner. The same task design may provoke different levels of practice load for different people and even for the same learner in different situations. Biological (e.g., metabolic or hormonal), psychological and social factors (such as activation, concentration or motivation) can modulate the effect of practice load, as has already been demonstrated in applying physiological loads (e.g., Elferink–Gemser, Visscher, van Duijn & Lemmink 2006; Lacaille, Masters & Heath, 2004; Pacienti, Meeusen, Buyse, De Schutter & De Meirleir, 2004).

In the final part of this paper we will review how motor variability, applied to facilitate motor learning, can be identified as practice load with the aim to interpret the effects of variable practice under the proposed model.

Variability as practice load

According to the previous rationale, we propose to consider variable practice as practice load. By practicing under variable practice conditions, the equilibrium of the system is challenged, and fluctuations in behaviour will be observed during the process of finding new system configurations adapted to the task constraints, thereby leading to a temporary loss of performance. Following the proposed model, having applied the practice load, and after the necessary recovery time, the learner will acquire higher levels of performance compared to those he showed before the intervention. Some studies in which the variable practice has not demonstrated improved performance compared to constant practice have only assessed the effects in a pretest-posttest design, without measuring performance after rest periods in a retention test (e.g., Breslin, Hodges, Steenson & Williams 2012). This is one of the issues we propose should be considered to explain the controversial results found by applying variable practice. To clearly assess the effect of a given practice load, it is necessary to analyse the effects on a retention test after a period of rest (or after a reduction in the magnitude of the load). In line with this assumption, in an experiment about learning basketball free throws (Hernandez-Davo, Urbán, Morón, Reina & Moreno, 2014), a group of young players were trained for three weeks (9 sessions) under constant practice conditions. After three weeks, accuracy increased. Subsequently, the same players practiced under variable conditions (9 more sessions), modifying factors such as the position, speed or orientation of movement. After variable practice, no better results were observed in accuracy and, in fact, lower performance values were obtained. However, after a two week rest period, the players showed significantly increased accuracy, exceeding the results obtained after constant practice. This increase in accuracy was maintained four weeks after the post-test (Figure 3).

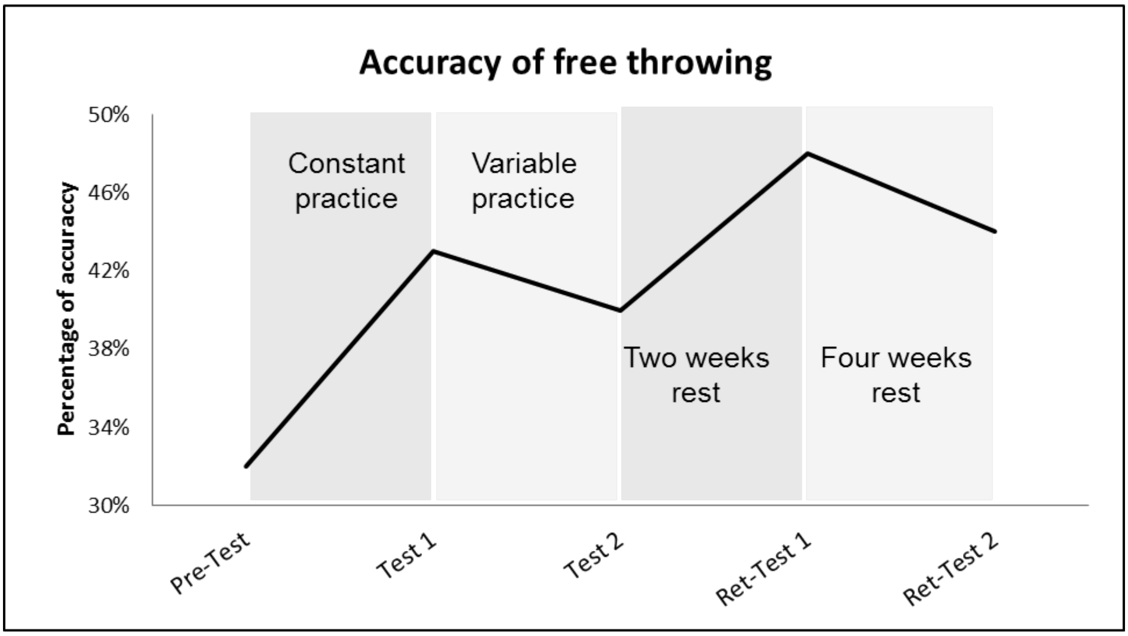

Figure 3: Free throw accuracy in young basketball players trained consecutively under constant practice (9 sessions) and under variable practice (9 sessions) conditions. Two weeks and four weeks retention tests are showed. (Adapted from Hernandez-Davo, Urbán, Morón, Reina & Moreno 2014).

Following the proposed model, considering variable practice as increased practice load can facilitate interpretation of the somewhat contradictory results in the scientific literature regarding the relationship between motor learning and such variables as age, task, or context (Schmidt & Lee, 2005). Ranganathan and Newell (2013), in a review on the characteristics and effects of variable practice, noted that variable practice should be approached from a multidimensional perspective due to the multiple mechanisms by which it influences learning. Ranganathan and Newell outlined the main effects of variable practice, which include improved ability to generalize and transfer learning to novel conditions, improved flexibility of the motor pattern and the emergence of optimal solutions adapted to learner characteristics and task conditions. We will explore to what extent the concept of variable practice load, developed from the proposed model, can be helpful to facilitate the task design to achieve these effects.

Variability, generalization and practice load

Schema theory (Schmidt, 1975) emphasized the ability to generalize as one of the advantages of the variable practice. Ranganathan and Newell (2013) suggested that structured variability in the task goal can lead to generalization and may be important in contexts where transfer of learning to novel task conditions is required. Variation may be useful not only in learning movement parameters but also in helping participants with structural learning (Braun et al., 2009).

Braun et al. proposed learning cycling as an example of improving generalization by variable practice. Variable practice alternating different types of bicycles allows the learner to explore general rules for how control parameters covary for the bikes. The set of bicycles lie on a low-dimensional parameter space, termed a structure. Learning such a structure will facilitate the exploration of the parameter space for a new bicycle, facilitating generalization and accelerating learning with a new bicycle. Given this principle and the issues discussed in relation to practice load, this generalization will be limited to the control parameter space covered by the range of variation of the different types of bicycles practiced.

Generalization would be more effective when the range of variation of practice falls within the parameter space of variation. Very small variations or few differences between the bicycles will lead to lower ability to generalize but more specific training. On the other hand, large variations will lead to greater generalization, but less specific training. For example, if the rider practices only with racing bikes varying specifications, weights and dimensions, he will have the ability to generalize and adapt to a new racing bike provided by a new manufacturer. However, if he practices with different types of bicycles in a wider range of variation (including racing, mountain or trial bikes), the practice will facilitate more rapid adaptation to a wider variety of bicycles but the training will be less specific. This last situation may facilitate generalization in a potentially unwanted way, mostly if he is seeking expertise in racing cycling sport. Thus, the magnitude of the variable practice load will provoke different effects, in this case in relation to generalization when the learner faces new skills. The variability of practice should be designed to facilitate variations in a delimited parameter space, according to the characteristics of the learner, the task and learning objectives.

Variable practice load and optimal patterns of coordination

We have previously noted that variable practice may facilitate the emergence of optimal patterns of coordination adjusted to individual characteristics and environmental conditions, and may aim to acquire flexibility in a given motor pattern (through variations at the execution redundancy or at the task goal level, respectively, see Ranganathan & Newell, 2013, for a review). From our perspective, the two aims are directly related. When a learner practices a skill, the first effect observed during the process of learning is that this ability becomes more stable and thus more resistant to perturbations (Davids et al, 2008). Stability does not necessarily mean greater consistency, but more resistance. Indeed the more stable behaviour will be that with the greater adaptability. We recall here the previously proposed idea that higher performance is associated with greater ability to adapt. The behaviour of a complex system is continuously exposed to multiple sources of perturbations, and it will be more stable as it becomes more flexible and able to adjust to the continuously changing conditions of the environment. Therefore, the optimal movement pattern, which takes into consideration the characteristics of the individual and the context, and the flexibility of the pattern are closely linked, if not the same matter.

Several previous studies have applied variations in practice such as applying perturbations or noise during the execution to facilitate the learning of the most optimal motor solution to allow effective rapid adaptation in a changing environment. We want to note for their relevance in the last year those studies from the differential learning perspective (Frank, Michelbrink, Beckmann & Schollhorn, 2008; Savelsberg et al., 2010). One of the fundamental bases of this approach is the idea of introducing noise during practice to improve performance, demonstrated previously in the physical and sensory domains and referred to as stochastic resonance. This phenomenon fits adequately with the principles of practice load, hyperstasis and the adaptation processes asserted in this manuscript.

The differential learning approach suggests utilizing the fluctuations in human movement to induce self-organizing processes into the learner taking advantage of individual movement and learning characteristics. A large variety of exercises are offered to the learner during the acquisition phase, and the learner is then faced with extending the whole range of possible solutions for a specific task. The fluctuations during practice are considered necessary for functional adaptation and the discovery of an individually specific, optimal way to perform the particular skill. This way, the addition of noise during the learning process facilitate the detection of the ideal movement and adapting more quickly to a new situation in a more adequate way (Savelsberg et al., 2010)

One of the issues raised by the differential learning approach is that there is an optimal level of noise to enhance the effect of variations in practice. Too much or too little noise might have low effect on facilitating learning. As argued in the stochastic resonance phenomenon, the addition of noise can facilitate detection of weak signals or stimuli below a certain threshold (Moss, Ward & Sannita, 2004). The phenomenon of stochastic resonance takes into account three basic elements: a threshold, a subthreshold stimulus and noise (Gingl, Kiss & Moss, 1995). These three ingredients are continuously present in nature. By applying an appropriate level of noise on a weak, or sub-threshold signal, signal peaks exceeding the threshold make the signal distinguishable. The application of noise must be random and as the signal level increases, the probability of exceeding the threshold increases, allowing an adequate perception of the signal. The intensity of the applied noise determines the optimal identification of the signal. Very low noise levels will not exceed the threshold, and very high levels will always exceed it. This phenomenon occurs mainly in nonlinear complex systems.

In strictly linear systems, the addition of noise to either the system or the stimulus only degrades the measures of signal quality (Moss et al., 2004).

Applying these principles to motor learning from our perspective, we propose to imagine a high-level athlete executing repeatedly a specific movement as the unique method to improve his performance for competition. There may come a time when the consistency of the gesture will be sufficiently high that the practice ceases to be a relevant stimulus. The simple repetition of the gesture will not be a stimulus strong enough to facilitate the exploratory processes needed for adaptation and learning. Applying noise would increase the magnitude of the practice load and will facilitate the system capacity to detect initially weak stimuli and facilitate the discovery of an individually specific way for the athlete to perform the skill. To consider variable practice under the paradigm of practice load is therefore related to the principles of the differential learning approach and close to stochastic resonance principles. Very high or very low levels variable practice result in little or no improvement of learning. However, the approximations from the theory of differential learning have not yet addressed the question of quantifying the appropriate level of noise to optimize learning, and further research in this regard is required.

Final remarks and future applications

During the last 50 years, several studies have attempted to test the usefulness of variability of practice in motor learning. Despite the fact that there is still some controversy regarding the results of some studies, most of the studies have proved that variability as an inherent human characteristic plays a functional role, allowing the organism to explore the environment. Variability is therefore considered a key element in adaptation processes (Button, Seifert, O'Donovan & Davids, 2014). In this manuscript, we have reviewed the relationship between variable practice and the adaptation processes on the basis of allostasis and GAS. The concept of practice load, based on these principles, can serve as a useful framework in designing tasks to facilitate and optimize motor learning.

Most of the studies mentioned above have tried to compare constant practice versus variable practice. However, as we have noted previously, variability is an unavoidable property of all biological systems. It is not possible for a movement to be repeated exactly twice and for every movement to be different in a continuously different environment. According to this approach, consistent practice is not really possible. In reality, the experiments compare different levels of induced variability during practice, most frequently comparing very low levels of variability (constant practice) to higher levels of variability of practice. The amount of induced variability in practice should be adjusted depending on the level of intrinsic variability within the participants, which is frequently (but not necessarily) related to their level of performance. Nevertheless, it has not usually been taken into account when experimenters established the procedures of variable practice. It is necessary to consider the variability of the environment in which the task will be performed, as well as the intrinsic characteristics of the task and the learner, to establish an adequate estimation of practice load and to subsequently guide the conclusions that can be drawn after an intervention.

In a previous work, we proposed some guidelines that could help in developing future studies of the effect of practice loads. These general principles, based on the perspective proposed, could be summarized as follows (adapted from Moreno & Ordoño, 2009):

1. *Analysing the task intrinsic dynamics.*

The intrinsic dynamics of the skill to be learned have to be previously analysed, and hence, performance criteria have to be established. The skills are performed in a changing environment. The magnitude in which the variations are expected to be found in the environment must be addressed because they will be important parameters of variation of the skill execution. This analysis should serve to recognize the range of variation in the generalization or range of flexibility that will be required for an adequate performance. This analysis also would facilitate identification of the main constraints limiting performance with the aim of orientating the progression of practice loads.

2. *Analysing the intrinsic dynamics of the learner.*

Learning is the result of the "fight" between the intrinsic dynamics of the learner and the dynamics of the task and the environment. Thus, the analysis of the characteristics of the learner should allow knowing what conditions of the skills are available to cope with the task and which are still far from their current capabilities, trying to avoid both very low and very high practice load. Likewise, measuring the intrinsic variability, both execution and goal related, during performance of the skill would help to adjust the load of variability in practice.

3. *Adjusting practice load.*

The learning tasks should be designed as practice loads with a load level superior to the demands to which the learner is currently adapted to facilitate a new level of adaptation (hyperstasis). Tasks must be designed with a difficulty level the learner has to cope with and thus, increase the learner's ability to overcome these difficulties with efficient patterns.

We want to emphasize again that the practice load is proposed with vector properties and must consider not only the magnitude but also the direction of the load. This means that the most appropriate magnitude and range of variation to produce the desired adaptation should be determined. Regarding the generalization effects, variable practice should be designed within a specific range of generalization, trying to optimize practice time. The practice variability in conditions that are far from the general rules for how the control parameters covary for different conditions around the skill can lead to unintentional adaptations. In relation to optimization and flexibility of movement pattern during learning, we propose variations in the practice that allow to solve the task within the "goal-equivalent manifold" (Cusumano & Cesari, 2006) or around the redundant task space of elemental variables (good variance) (Latash, Scholz, & Schöner, 2002; Scholz & Schoner, 1999). Variations far from the family of solutions that solve the skill would not facilitate learning and may cause unwanted adaptations.

4. *Establishing assessments procedures.*

Assessment is an essential element in any learning process, and from our perspective is especially relevant to establishing how far an athlete is able to perform effectively with a given practice load and, therefore, to identifying the necessity to modify the magnitude or direction of the load. The assessment should include aspects related to the outcome of the action as well as the execution characteristics for knowing to what extent the practice load is affecting the motor behaviour. It is suggested to use a scanning procedure (Yamanashi, Kawato, & Suzuki, 1980 Zanone & Kelso, 1992) varying intentionally an order parameter to scan the perceptual motor landscape and recognize stable and unstable regions.

We will use a tennis serve training situation as a vehicle to exemplify some details of the steps suggested above. Hence, the variations in practice should be related to the intrinsic characteristics of the task goal and execution of the tennis serve. Regarding the task goal, the tennis serve is constrained by three key elements: the baseline (behind which the player has to serve), the net (which the ball must pass over) and the boundaries of the service box (where the ball should be sent to). Those conditions are not completely stable because the player can be located at a varying distance from the baseline and the dimensions of the service box allow variations where the ball can bounce. Regarding the execution of the serve, we must also take into account some elements which are needed to achieve the maximum efficiency. For example, the ball should be hit over the head and the body should be projected forward, searching to hit the ball high enough to pass over the net with the higher speed and accuracy as possible. Other factors such as the movement coordination, the grip, or the ball toss, will vary depending on the characteristics of the individual or on tactical aspects, being parameters of the "favourite" pattern showed by the tennis player.

In the design of the practice load we might ask the player to serve varying the distances from the net. Variations including from five meters in front of the baseline to five meters behind the baseline will mean very high practice load which would cause changes and adaptations in the serve pattern in a direction that may not be intended. On the contrary, if the variations are only in a range of few centimetres around the baseline, the load could be a very weak stimulus causing no significant adaptations.

Nevertheless, the estimation of the practice load will not be complete if we do not consider the intrinsic characteristics of the tennis player (e.g. age, performance level, morphological or functional characteristics…). An elite tennis player will show less variability performing a serve both at the execution and at the goal level, than a novice player. Thus, variations of a few centimetres in the distance to the baseline could be a really significant stimulus for the elite player due to his higher ability to perceive small changes in the movement or in the environment (Williams and Ward 2003). Thus, the same level of induced variability could be a low practice load for a novice player, and be an excessive practice load for a high skilled player (depending on the intrinsic variability expressed by the player in the specific skill and environment).

This is just one example of variation that can be manipulated to increase the practice load according the proposed model. Practice loads should include simultaneous variations of different parameters that vary naturally in the environment (the distance to the net, the lateral position or the location of the target) and in the execution (by varying the speed of the movement, the ball toss, body orientation, etc.). In a recent study we have applied some of these parameters to improve tennis serve of young players by variable practice (Hernandez-Davo, Urbán, Sarabia, Juan-Recio & Moreno, 2014). To apply variations not naturally present in the tennis serve event (variations in the implements, balls, or including very different motor patterns) should be dealt with caution, as they could alter the direction of the practice load, leading to unwanted adaptations. The assessment of both the task and organism characteristics will enable us to adjust the practice load to optimize learning.

Finally we want to note that this proposal would not only be applied to variable practice, but it is intended as a general model that may help to explain other basic processes of learning. The perspective of practice load could facilitate the understanding of the effects of other interventions in motor learning. For example, contextual interference (CI) in which the system is exposed to different practice scheduling for learning multiple skills can be reinterpreted as interference load. The more the CI proposed (blocked, serial or random), the more the resistance to instability of the patterns in the perceptual-motor landscape. The load of IC characterized by continuous changes of tasks, would explain the positive results of CI in retention tests (Moreno, Avila, Damas, Garcia, Luis, Reina & Ruiz, 2003). Other strategies of practice, such as analytical versus global approaches to practice or the more recent studies on representative task design (Davids, Brymer, Seifert & Orth, 2014) can be related to the direction of practice load, providing specific adaptations depending on the skills learned. Latent learning typical of massed practice can be explained by the recovery processes after practice as predicted in the GAS and associated with high rates of performance after a rest period (Garcia, Moreno, Reina, Menayo & Fuentes 2008). These issues and other topics of motor learning could be studied in the light of this proposal to evaluate the utility of this model.

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