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Motor control

PERFORMANCE SPIRAL EFFECTS ON MOTOR LEARNING: THE CASE OF TENNIS SERVE

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Summary

Performance-learning distinction necessitates the development of novel models to measure performance meaningfully, i.e. in direct relation to the "invisible" learning. Such models should have direct practical implications. Performance Spiral (PS) is such a model and incorporates findings from motor learning & control disciplines (Contextual Interference, practice schedules, dynamic system theory), Sports Training (speed-assisted / resisted training) and insights from traditional schools in music and sports (Slow Practice). 11 subjects (age M=31, intermediate level) in two groups, one control (6) and one PS-trained (5) were measured in speed and accuracy progression of tennis serve, as an improvement in speed or accuracy would would denote motor learning. After two months, while the classically-trained control group did not show any statistically significant change (a = 0.05) in performance, the PS-trained group increased their accuracy by 50 % (pre-PS: 32% balls in, post-PS 64% balls in), marking a significant change (a = 0.05). PS model is effective in producing motor learning in tennis serve. The possible mechanism explaining learning in PS-trained individuals is discussed. Future directions are given regarding the application of PS model to larger populations and other sports / activities.

Keywords: performance spiral, speed-accuracy trade-off, performance-learning distinction, contextual interference, perturbations, attacking attractor, slow practice, tennis serve

Introduction

Teachers, trainers and performers alike constantly seek better i.e. more effective and simpler ways to practice. Moreover, it is not a secret that contrary to everyone's wishes, there is no single simple step-by-step methodology for motor skills learning; however, practitioners keep "demanding simple 'how-to' rules of human movements when these simple answers often do not exist" (Knudson, 2007, p. 30). Performance Spiral is not such a reductionist "how-to" rule, but nevertheless, it has some inherent characteristics that offer to the practitioners a convenient vehicle to direct their efforts towards a more holistic plan of practice for a wide variety of motor skills. Moreover, it is an *a priori* perceived model which makes it methodologically superior according to the mathematical predicates of episteme, but not *scientia*, or, science (Παπαγεωργίου & Λέκκας, 2014). Trying to verify a model via experiments is a logical mistake (affirming the consequent). However, since contemporary scientific culture finds experiments necessary, an experimental procedure was included.

Skill learning and *performance* are paradoxically an inseparable pair: different, even contradictory, yet the invisible one – learning – cannot be assessed without its visible counterpart – performance (Kantak & Winstein, 2012, p. 229; R. A. Schmidt & Wrisberg, 2008, p. 258; Shmuelof, Krakauer, & Mazzoni, 2012, p. 589). However, when one attempts to manipulate learning by performance interventions, they surprisingly hinder learning (Fischman, 2007, p. 69).

What are the practical applications of the former for the practitioner (trainer, rehabilitator, teacher etc.), apart from the obvious conclusion that one cannot *directly* infer learning from performance? Performance can be described and evaluated by performance- (or "learning-") curves that show the progress in an outcome-measure of performance, such as error, reaction time (Edwards, 2010, pp. 486–488; Magill, 2007, pp. 247–254; R. A. Schmidt & Wrisberg, 2008, pp. 204–205). The chosen measure (speed & accuracy) is chosen as the most suitable (relevant) way to measure performance according to the task at hand; for example, to measure reflexes and quickness in decision-making (motor skills), reaction time measures are appropriate, which is not the case should one wishes to measure e.g. a tennis serve. However, performance improvement might be only temporary; in such cases we cannot consider it "learning" – only a relatively permanent improvement is regarded as learning (Kantak, 2012).

What would be a suitable measure for such a long-term improvement i.e., *learning,* in a tennis serve? There are many skills and movements in sports (and other actions) one may wish to both describe and evaluate. These include – apart from racketsport strokes – golf, baseball and volleyball shots, judo throws and even piano playing skills (not sequence playing, but distinct skilful pressing of the keys), to name a few. The most appropriate measure would be one that *measures their speed and accuracy,* capturing a balanced progression in the speed-accuracy trade-off (Fitts, 1954). Indeed, Shmuelof et al. (2012) define skill learning as a change in the speed-accuracy trade-off: "We sampled subjects' motor ability, defined as performance on a speed–accuracy task, across multiple levels of difficulty before and after training, which elicited performance that ranged from very successful to poor" (Shmuelof, Krakauer, & Mazzoni, 2012, p. 589).

By the definition of Shmuelof et al. (2012), a *ceteris paribus* increase in speed, qualifies for skill-learning. Furthermore, maximum speed in itself in activities such as sports is sometimes not enough; the production of force F is a requisite as well. Skills in sports can result in the application of force for a time period t, which results in the production of *impulse* ($F = J / \Delta t$, $J = \Delta P$ / J: impulse; P: momentum), which denotes the change in the momentum of a body or of a system (such as the arm-racket system). When a collision takes place, it is not only the force that matters, but how long did the force apply. Because $J = F\Delta t$, for a constant J, when Δt decreases significantly, F proportionally increases. In a racket-ball system (or bat-ball, hand-ball system etc.), *contact-time* is affected by the elastic properties of the materials (e.g. half-periods of both racket's strings and ball – even though only ball's half period counts as it is lesser – Brody, 1979). Therefore, successful performance is dependent on the ability of the system to produce, *ceteris paribus,* high forces. Inversely, high performance, i.e. bodies (e.g. tennis balls or hands hitting the clavier in Tchaikovsky's 1st piano concerto's octaves) travelling at high speeds with the same (good) trajectory accuracy, is denoted by a forceful *and* fast movement. Force is proportional to speed as $\Sigma F = m(V / t)$ (V: velocity). The improvement in speed and force (with the *ceteris paribus* clause always in effect), makes a new performance curve, which may, or may not be a straight line, however here it will be depicted as a straight line for simplicity purposes (Magill 2007 p. 250-251). The adapted performance curve is depicted in figure 1.

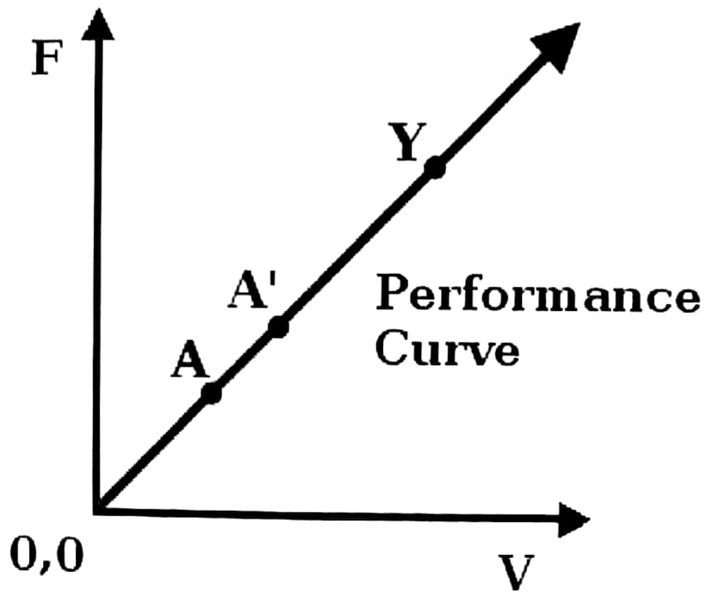
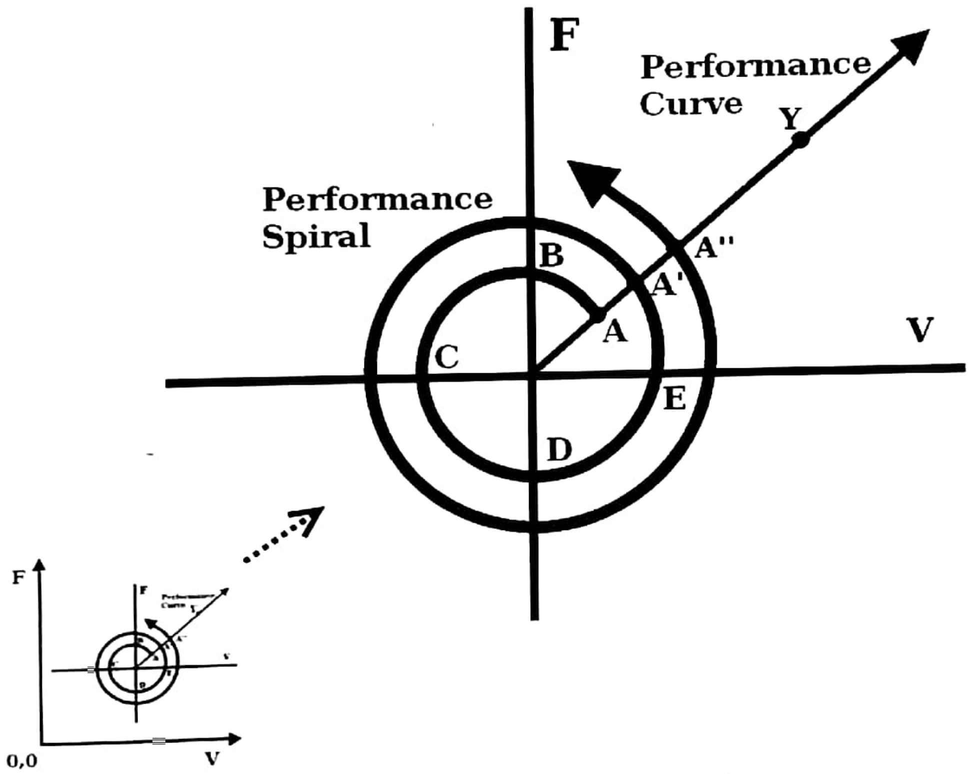


Figure 1. The Force-Velocity Performance Curve for a definite accuracy level. A: Initial performance, A': some intermediate performance, Y: Expert performance.

Despite the vast amount of findings that support the learning-performance distinction, teachers and trainers that are not following some major school tradition (e.g. Iwama Aikido, or one of the Russian Piano Schools etc.), are inclined to intuitively adopt a performance-based approach to learning. Researchers that criticized such approaches, include – among others – R. Schmidt & Bjork (as early as 1992) and Bain & McGown, 2011. In figure 1, this translates as someone trying to go from point A directly to point A' and from there continue until one can (hopefully) make it to Y (expert performance). However, according to the aforementioned issues, improving performance directly is not the optimal way neither to learn (if it is at all...), nor to successfully increase performance in the long term. Trying to improve performance by trying to address causes on one dimension only, neglecting the variety of parameters that affect motor learning (K. A. Ericsson & Lehmann, 1996; Rossum, 2009, p. 764) seems not a very promising strategy.

Already since 1994, Bloomfield & Ackland in their *Applied Anatomy and Biomechanics in Sport*, presented a wide variety of qualitatively different exercises to develop speed. Popular books, no less, such as *Sports Speed* (Dintiman, Ward, & Tellez, 1998), support that to increase sport specific speed, one must engage in a variety of training activities and include different kinds of exercises, namely *plyometrics, ballistics, sport loading* (speed-resisted training), *overspeed training* (speed-assisted training) etc. Research in the field of sport training and conditioning is also supportive regarding the beneficial effects of diverse programs that include plyometrics, strength training (e.g. weights), sport loading (e.g. resisted sprint training), eccentric training, overspeed training etc. (for example see Cook, Beaven, & Kilduff, 2013; Pienaar & Coetzee, 2013; Upton, 2011). Ideally, a model that both describes and evaluates performance would also explain and predict the development of an individual by incorporating the major components of a varied developmental program. Another equally important characteristic of such a model, if it is to be broadly used in practice, is to be simple, comprehensible and *elegant.*

By taking as the center of the graph an internal point in the first quartile, and by extending its axes, a four-dimensional system occurs. Each dimension expresses a combination of the two parameters (force-velocity), hence a different dimension is created every time: *Sport Loading, Slow Practice, Flow Practice* and *Overspeed Training.* A spiral connects all the four dimensions, leading indirectly to the next, higher level of performance (figure 2).



A Initial capacity for performing.
A-B Force increases, Velocity Decreases.
B Point of increased Force / Resistance in training: **Sport Loading** (Speed-Resisted training).
B-C Force decreases, Velocity decreases.
C Point of least Velocity: **Slow Practice.**
C-D Force decreases, Velocity increases.
D Point of least Force / Resistance: **Flow Practice.**
D-E Force increases, Velocity increases.
E Point of speed training: **Overspeed Training** (Speed-Assisted training).
A' A new point on the performance curve reached indirectly after one cycle.
A'' Performance continues to improve after each cycle.

Figure 2. The Performance Spiral.

All the constituents of the models are consistently found in training programs of major traditional schools in martial arts and music. The succession is also supported: overspeed training, the last step, is the most demanding one in terms of technical and physical capacities. The previous steps ensure a safer transition to this last step. Sport loading is related to the strengthening / warming up of the relevant musculature in order for slow practice to be introduced: the deliberate practice phase (Papageorgiou, 2014). Flow practice follows next, relaxing and thus preparing the musculature to endure overspeed training.

Slow practice is a practicing technique that has not been the object of any extensive research, despite the central position it holds in major traditional martial arts and music schools. Furthermore, the findings are ambiguous, attributing to slow practice both benefits (Magill, 2007, p. 414 citing Walter & Swinnen 1992) and drawbacks (Schmidt & Wrisberg 2008 p.242-243). However, in this model, it plays a central role for two reasons, namely the high quality practice of technique *per se* it provides, which (correct technique) is a prerequisite for high performance, and the generalization of the skill gains to higher speeds (attacking attractor model).

The attractor concept is borrowed from dynamical systems theory that has strongly emerged as both a competing and sometimes complementing alternative to the strongly emergent top-down cognitive-based theories, such as Schmidt's schema theory (Edwards, 2010, p. 142; for schema theory see R. Schmidt, 1975, 2003). Schmidt (2003 p.373) argues that (his) motor program theory is at its best when it comes to explaining the learning process. However, recent dynamical system models have gone a long way in that respect as well – as Schmidt himself acknowledges (Sherwood & Lee, 2003, p. 373; *cf.* L. P. Latash, 1998). At any rate, recognizing the differences in the two theories (or better, models[1]), the dynamical, self-organizing synergistic nature of attractors (Kelso, 1998) qualifies for the utilization of the attractor notion in this work. Interchangeably, the use of *motor programs* instead of *attractor states* would seem almost just as adequate, as in many respects, traditional motor programs and dynamical systems share common characteristics (Summers & Anson, 2009, p. 572). Moreover, many theorists have proposed hybrid models of skilled movements that are dynamically distributed in brain motor-maps being (the movements) constrained by motor programs (engrams?) (Amazeen, 2002, p. 249; Monfils, Plautz, & Kleim, 2005, p. 480; Morris, Summers, Matyas, & Iansek, 1994, p. 745; Summers & Anson, 2009, p. 572). "Engrams" were in-

1. A theory (here: as *θεωρία*, not *θεώρηση*) is without any real content, applicable to any phenomenon that may be described using an interpretation of the said theory. A model is an interpreted theory. Theories are found in mathematics.

troduced by N. Bernstein, and were later conceptually evolved into motor programs (M. L. Latash, 2008, p. 57), therefore it is sometimes confusing to understand what modern researchers really mean when using the word "engram" (Monfils, Plautz, & Kleim, 2005; Morris, Summers, Matyas, & Iansek, 1994, p. 745). Moreover, there is still a lack of consensus for both the motor programs (Summers & Anson 2009 p. 566) and the dynamic systems' exact physical substrates (M. L. Latash, 2008, pp. 360–363).

Proposing a new model for motor learning, as well as applying it in practice (in tennis serve) is the purpose of this study.

Research Hypothesis: There is a difference inside the speed-accuracy graph between baseline and final values.

2. Materials and Methods

2.1. Participants

For this preliminary assessment of the PS model, 11 healthy participants (7 males, 4 females) from a local tennis club (Advantage Tennis Club) in Athens, Greece were included. All participants were between the ages of 25-35 (M=31, one female), right and left handed. Participants were ranked as intermediate tennis players.

Four trainers cooperated for this study, two formerly seeded tennis players (one internationally), and two professional tennis trainers with a university degree in Sport Science (specialized in tennis).

2.2. Task

11 participants were divided into two groups: 6 in the control group 5 and in the PS-trained group. The first group was taught the tennis serve the traditional way (trying to move directly from A to A' in the Performance Curve). The second group was instructed according to the PS model in the following way:

1st session: Sport Loading,
2nd session: Slow Practice,
3d session: Flow Practice,
4th session: Overspeed Training,
= 1 cycle (two weeks).

4 such cycles were completed in a period of 8 weeks (2 months), that is, one cycle every 2 weeks, each cycle consisting of 4 training sessions. Verbal and live demonstration of the skill were provided. Summary feedback was used.

The materials used for the study were selected so that it would be easy for any trainer to acquire them. Specifically, Sport Loading was achieved by tying an aerodynamic barrier on the face of the racket, and by using balls with twice the weight of a regular tennis ball. Slow practice was executed with and without hitting a tennis ball, by instructing the participants to go "as slow as possible all the way". Flow practice was practiced without hitting any ball, and instead of tennis rackets participants used badminton rackets. Finally, overspeed training was conducted with regular rackets and balls, while the trainer actively accelerated the racket from the elbows of the participants during the acceleration phase. The PS sessions lasted 15 minutes at every lesson.

2.3 Variables and Testing

Service-speed of balls that landed inside the service box and percentage of balls inside the service box were measured. Measurements were made in the beginning to acquire baseline values, and after two months for both groups.

Measurements, using a portable radar-gun (PocketRadar, + / - 2 Km / h in 600 Km / h accuracy – factory specifications) were made at the beginning of the program and at the end of the program, two months later. To ensure that *learning* was recorded, delayed retention was assessed by making measurements in the beginning of the tennis lesson, before the individuals had any training, and after 3 days from the last training session of the program. Individuals warmed up their shoulders (without rackets), served two balls, and then were measured for another ten balls in a row. The same procedure was followed for the transfer test, which included hitting smash (for delayed retention & transfer tests see Kantak 2012; For the testing effect see Roediger & Karpicke 2006). All the participants, before the final set of measurements, after two months, were explicitly asked whether they felt they had improved or not. Participants, from the broader area of Athens, Greece, were generally uncooperative during the study.

3. Results

1. We ran an ANCOVA with: (a) *serve speed* after as the dependent variable; (b) the control and the PS groups as levels of the independent variable, (group); and (c) the baseline serve speed (speed 1) as the covariate, (baseline). $F(1,7)=0.917$, $p=0.37$ (No significance).

2. We ran an ANCOVA with: (a) accuracy after as the dependent variable; (b) the control and the PS groups as levels of the independent variable, (group); and (c) the baseline accuracy (Accuracy1) as the covariate. $F(1,8)=14.734$, $p=0.005$ (Significance).

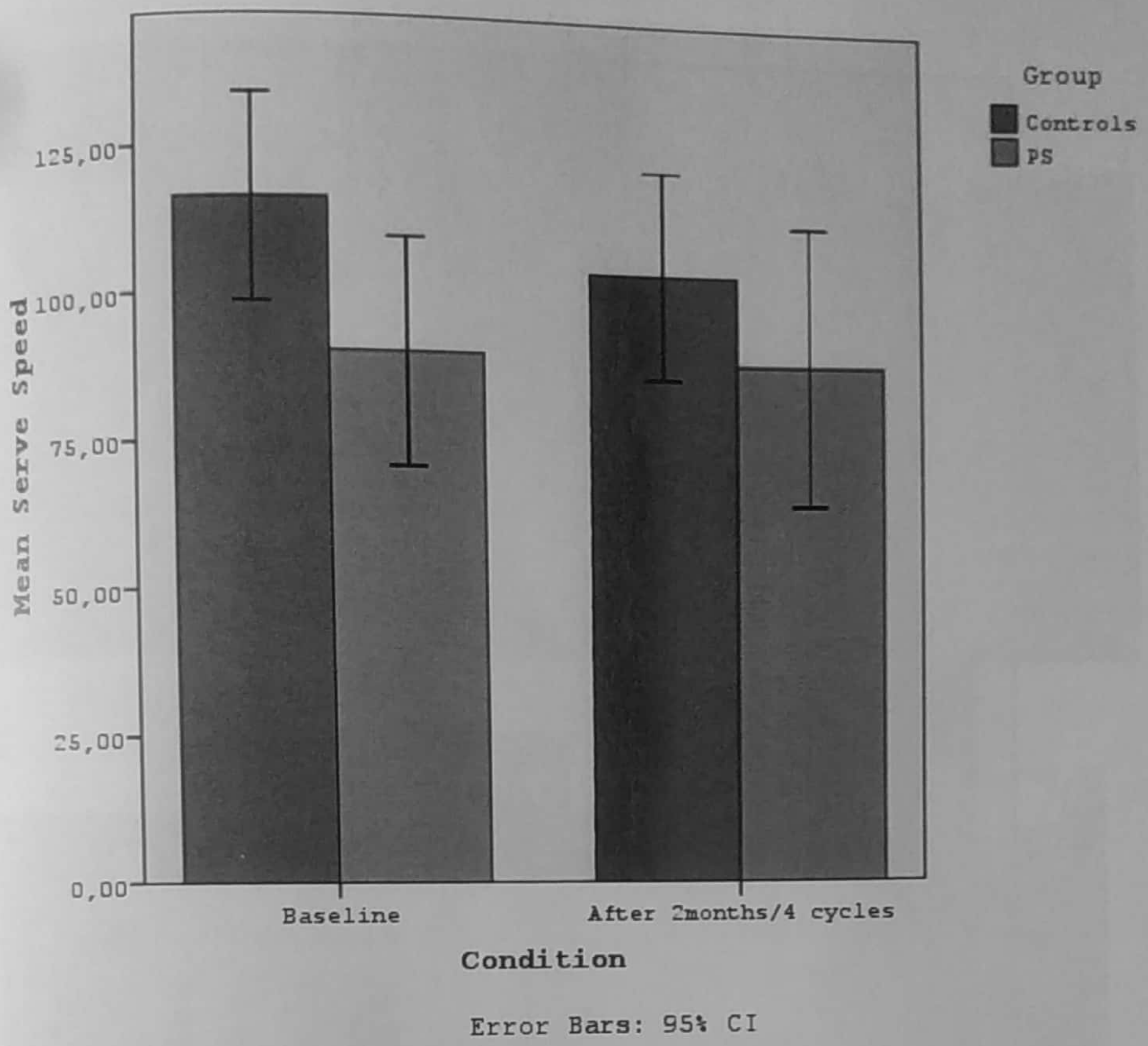


Figure 3
Mean serve speed: Control group vs. PS group, before and after intervention.

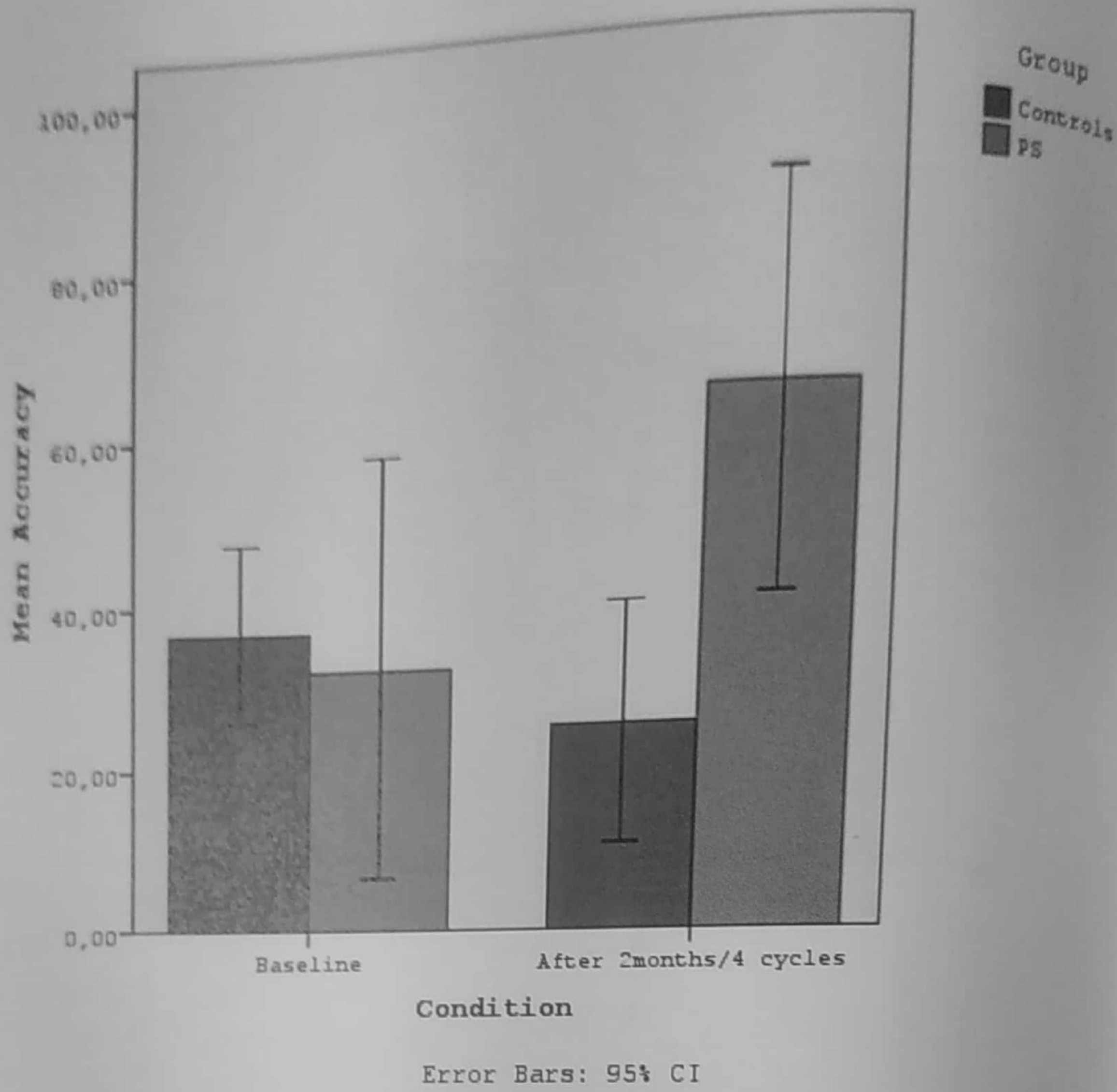


Figure 4
Mean accuracy: Control group vs. PS group, before and after intervention.

Pic. 1

Pic. 2

Pic. 3

Pic. 4

Pictures 1-4. In pic. 3 The elbow-drop of the male subject (from control group), denotes absence of upper arm internal rotation. PS-trained female in pic. 4 is more successful in internally rotating her upper arm while keeping her elbow higher after two months. Pics. 1 & 2 are snapshots (after contact point) of the same serves depicted in pics. 3 & 4.

The results show an improvement in accuracy by 50 % in the PS-trained group (pre-PS: 32% balls in, post-PS 64% balls in), marking a significant change ($\alpha = 0.05$). The transfer test included smash-hits. However, apart from accuracy, no other measure improved significantly. It should be noted that the data for accuracy come from the 3-day delayed retention test.

3. Discussion

While only the tennis serve was the experimental focus here, the same general ideas might as well be generalizable to other motor skills. Implications of the Attacking Attractor model relevant to this study will be presented here; for a more thorough analysis of the theoretical model please refer to Papageorgiou 2016.

Among all the parameters measured, only accuracy improved in a statistically significant way. The lack of improvement in speed might be because control (precision) improves before speed; but as biomechanics of the movement improve, speed is likely to follow. In tennis serve, a biomechanical improvement in the technique consists, among other factors, of the more pronounced upper arm internal rotation, which contributes ~40% to impact racket velocity – forearm pronation contributing ~5% (Elliott, 2006). PS-trained subjects after two months increased upper arm internal rotation (forearm pronation, which contributes ~5% to impact racket velocity was the same for both groups), as was qualitatively asserted. Further training would arguably increase even more upper arm internal rotation *vs.* flexion that is more salient in untrained individuals (see Pic. 1 & 3). In further, sufficiently longitudinal studies, the increase in speed may be recorded, after the stabilization of accuracy, which seemed to be the result of this intervention.

The data shown are from delayed retention tests. That is, they have a very good ecological validity since they are not affected by acute adaptations, but rather denote real motor learning (Kantak 2012). Smash speed and smash accuracy did not improve; although improvement would be welcome, this is also a positive outcome since they did not worsen as well: in motor skills, when the transferring effect takes place, it is not always for the best. Negative transfer is always a threat (Edwards 2010 p. 193-199).

One could go on and discuss the implications of the PS without trying to conceive the exact nature of the underlying mechanisms; however, an effort is made to provide an explanation. The theoretical background of this intervention is based on the Attacking Attractor model which combines Schmidt's motor programs with Bernstein's dynamic systems. The whole concept is based on a synthesis of the demon-of-the-endpoint (Latash 1998 pp.317-318), and the Chinese Room argument (Kim 1998 p.99): *The room analogy for non-linear attractor-shifts.*

In this example, an analogy is made between the physical configuration of a room (i.e. the brain), and the habits of an individual residing in it (the motor control system). The bottom-line is that the residing individual is able to pre-determine his automated motor behaviour in the said room by consciously pre-defining the configuration of the room. The physical structure of the room provides for the individual attractive spots, i.e. places he prefers over others. Such areas are the *attractor basins* in our analogy. Within these attractor basins, the individual may then act in an automated way that resembles motor programs. The attractor-shifts happen as the individual rearranges the room: at some given point during the process, another part of the room becomes more attractive.

The individual has not chosen *when* he feels to be more attracted, this emerged on its own right; the individual has chosen that they want to be attracted from a specific part of the room and *worked towards that goal*. The progression cannot be linear, as the change of established behaviour needs a sufficiently big motive to change. Still, the main message remains the same: attractors may exert influences bottom-up, but the creation of attractor states may be a deliberately controlled, in a top-down process, as long as the individual insists until another attractor basin is created. In this analogy, the person is the X, the "ghost in the machine" (Carpenter, 1996, p. 287), i.e. consciousness, and the external attractor states of the room are the internal attractor states in the CNS.

Regarding now the PS which led to superior motor learning in relation to traditional training protocols, as they are implemented nowadays by some professional tennis trainers: motor learning was defined as a change in the speed-accuracy trade-off (Shmuelof et al., 2012). However, motor learning could have been the contingent result of the random succession of the dimensions of the performance spiral, as they occur by the combination of the two axons (Force & Velocity). Are there any other reasons the arrangement of the four dimensions is an optimal one?

Motor learning, in dynamic system's theory, can be defined as developing deeper basins (or wells) of attraction which will be more stable and resistant to external perturbations (Edwards 2010 p.160). Perturbations themselves are critical for motor learning (Gandolfo, Mussa-Ivaldi, & E, 1996; Mansfield, Peters, Liu, & Maki, 2007, 2010; Schöllhorn, Willem, Mayer-Kress, Newell, & Michelbrink, 2009; Wei, Wert, & Kφrding, 2010). By including slow phases one is able to consciously form an attractor, and by following the other phases of the PS program one exposes the learner to perturbations caused by the fast phases of the program. By repeating the cycles, the basin deepens, and by repeating the cycles with increasing difficulty level (i.e. higher speed in overspeed training, bigger load in sport loading, slower in slow practice) one progressively increases the perturbations and further stretches the performance by avoiding arrested performance from occurring – as is predicted by the deliberate practice model (Ericsson, 2006; Papageorgiou, 2014). Slower practice presupposes better understanding of the movement and increased attentional skills. It is more critical in later stages of practice where the performer makes subtler errors (Magill 2007 p.271). It is possible that the manipulations proposed here, when taken separately have different effects, both ergogenic (Flow Practice, Montoya et al. 2009) and ergolytic (loading techniques, Southard & Groomer 2003). If all phases of the PS are executed within one session, the priming the first phase offers, followed by slow practice may have positive implications for recidivism issues, following the modern research on reconsolidation (Besnard, Caboche, & Laroche, 2012; Crossley, Ashby, & Maddox, 2012). Practicing *at least two* of the parts of the program (merging two sessions into one) should produce double the benefits, as previous research has shown that practicing two tasks in a random order, produces the same learning as practicing only one task within the same time constraints (Maslovat, Chus, Lee, & Franks, 2004).

The concept of introducing gradually more perturbations to increase Contextual Interference, and thus learning-effectiveness is an inherent component of the Differential Learning model of Schöllhorn et al. (2009). In their work they forward the notion of introducing stochastic perturbations through interventions such as variable practice, that increase in number (more noise) to produce more and better motor learning till the optimal level of perturbations is attained in Differential Learning (Schöllhorn et al. 2009 p. 330). PS model follows a similar way in order to introduce progressively more and increasingly variant stimuli (there are many ways to practice the parts of the PS: varying sport loading or overspeed training, utilizing different materials, implicating cognitive strategies or procedures etc.).

There are still other benefits. In non-linear motor control systems, due to the Freedom Degrees (FD's) problem Bernstein identified, when novices try to acquire a new multi-limb skill, they automatically freeze some FD's so they have less FD's to control (Gielen, van Bolhuis, & Vrijenhoek, 1998). Slow practice has "antifreeze" properties as it makes it possible to release all FD's while it "attacks" the pre-established attractors. Recidivism towards old attractor states, as well as loss of stability in the presence of perturbations are prevented during slow practice, while the ground for faster or more stable performance is prepared. Later, as performers improve through the PS, they will increase their speed and by doing so, at some point – at a *critical speed* – as the motor control system tries to remain stable, it will reorganize by means of a spontaneous, non-linear phase-shift of the coordination pattern around another attractor basin that will restore equilibrium and stability (Edwards 2010 pp. 157-158). This second attractor needs to be attacked too. In the PS, the increase in the level of Flow Practice means the increasing accuracy and duration with which one may practice very close to the boundary condition of the phase-shift, minimizing (but not trying to eliminate – see *testing effect*) the violations of the boundary between the two attractors. Flow practice in the PS, as is currently utilized by some major school traditions (like weapons training in Iwama Aikido), has received little – if any – attention as a training practice. Its idea is to perform the skill with less load than normal to focus on the flow of the movement and not on equipment.

There are skills that are better executed by a change in the coordination pattern in a definite critical speed. For example, piano octaves or some transitions between positions in martial arts are made possible by differentiating coordination patterns. The practice near the boundary condition of the phase shift (in this case from both sides of the critical speed thus deepening both attractor basins) might prove to produce more smooth and controllable transitions. A wider view (that includes many phase-shifts) would even include motor sequences (Katas, dances or whole musical pieces), an application of the PS worth investigating in the future, as empirical evidence show that the PS model is effective in learning *motor sequences* as well (used in e.g. Aikido and Karate). In such skills there is usually a predominant attractor – like the walking attractor is in the walk-run non-linear transition (Magill 2007 p. 152).

Sport loading (Speed-resisted training) has long been believed to increase performance as a skill-specific speed and explosive strength-training method (Harries, Lubans, & Callister, 2012; West et al., 2013). Here, an additionally proposed reason for its value is the perturbations it causes to the motor skill, especially if executed near the phase-shift speed of the skill. It may be viewed as a complementary strategy to Flow Practice that induces strength-specific adaptations as well.

Note that performance plateaus are predicted and explained by the competing attractor hypothesis, as the time period when the influence of two attractors is approximately equal. When the preferred attractor basin gets deep enough after deliberate practice, performance growth will restore. Studies mention that the period during the plateaus is not static, but despite evident performance gains, learning (i.e., attractor basin deepening) continues (Magill 2007 p. 259-260).

It is in order now to make some comments regarding the present study in relation to the concepts of *schedule of practice* and *perceived competitiveness*. While learners found the novel tasks imposed to them by the PS program were demanding, and while the results of each session highly exhibited the classic random practice characteristics (poor performance, albeit only initially in this study) – Magill, 2007; R. A. Schmidt & Wrisberg, 2008), when the PS group was asked prior to the final measurements about their expectations, they declared that they expected to perform *better*. The control group answered that they expected to perform the same (as was indeed the case). Because only one part of the PS per session was used, it might seem as a somewhat blocked practice, but trainers were instructed to vary the stimuli: change serving locations, change feedback and rhythm etc. This increased CI. By including more parts per session, CI is expected of course to further increase. But despite the level of CI used in this study and the intermediate performance in practice sessions, as participants acknowledged the benefits of the program before the final measurements took place, PS model seems to successfully address the issue of poor motivation in learners engaged in random-order training-schedules (Simon, Lee, & Cullen, 2008). In agreement with the Win-Shift, Lose-Stay method of Simon et al. (2008), here it is additionally proposed that learners could engage in peer-teaching activities utilizing by themselves the WSLS method (as would be requested by the teacher) and benefit from the multiple gains of peer-teaching as well (Magill 2007 p. 315-316).

Finally, trainers themselves found the PS model adequately understandable; this applies both to the ones that had sports science studies and the trainers that did not have formal sports science education.

4. Conclusion

The Performance Spiral is a simple and elegant method for the effective development of training schedules for motor *skills* and, possibly, motor *sequences* in a simple and elegant manner, stemming from its geometrical symmetry and simplicity. Its theoretical foundation is the attacking attractor model incorporating elements from vastly different approaches, from both motor programs and dynamic systems. The results of this study partly confirm the predictions of the PS in tennis serve, but due to constraints and the preliminary nature of this study, it may better be conceived as a starting point for future designs.

The next step might be to design further research protocols that would assess the Performance Spiral, or any conceivable and meaningful variation of it, with any number of restraints (time, order etc.) to any other set or sets of motor skills.

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