# Performance Spiral and the Attacking Attractor Model

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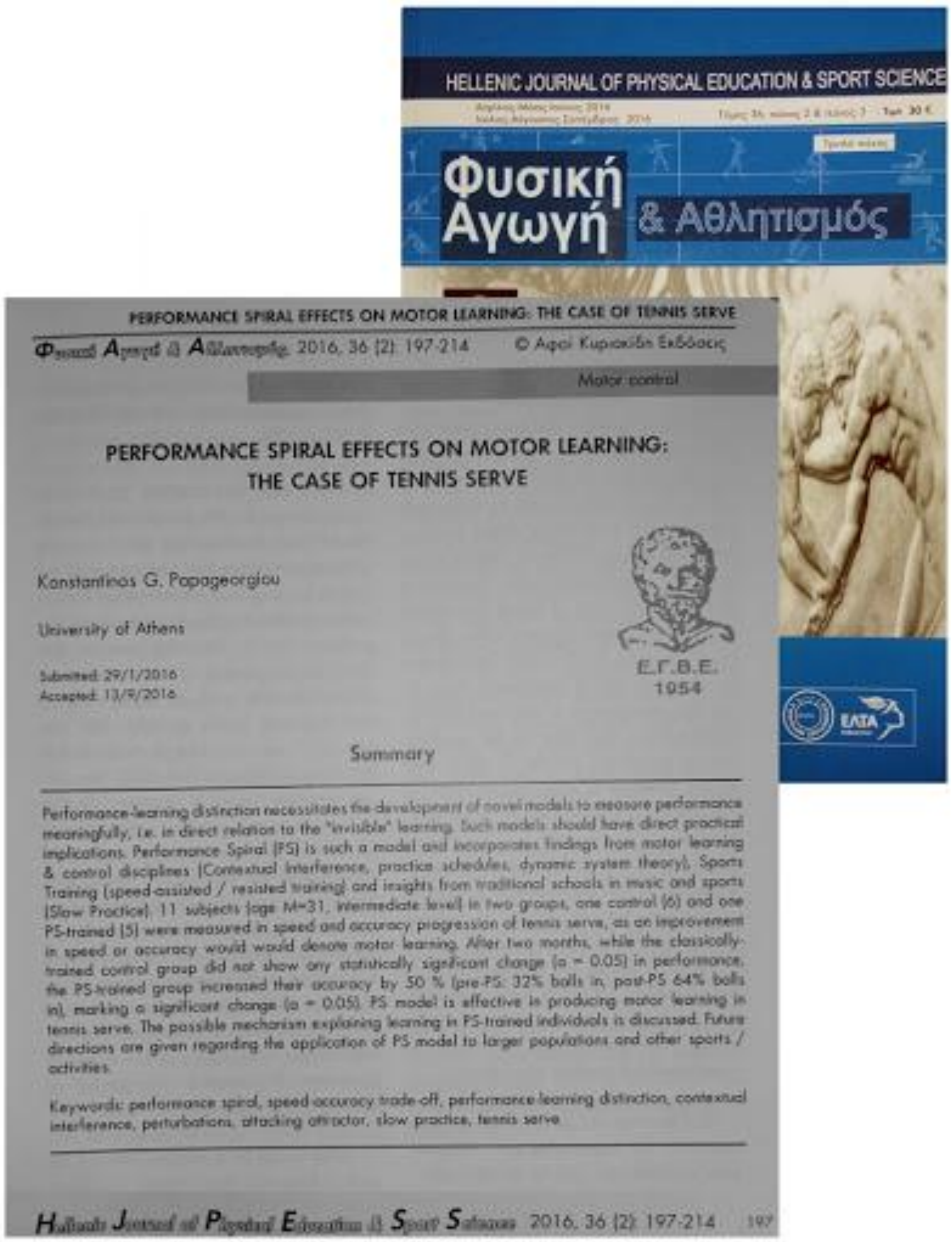




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Motor control

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 (α = 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 (α = 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

# 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 (Slow Practice) from traditional major schools in music and sports. 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, which would denote motor learning. After two months, while the classically-trained control group did not show any statistically significant change in performance, the PS-trained group increased their accuracy significantly. PS model is effective in producing motor learning in tennis serve. These preliminary results are discussed and future directions are given.

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

# 1 Introduction

*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)– and the aforementioned articles).

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 etc. (Edwards, 2010, pp. 486–488; Magill, 2007, pp. 247–254; R. A. Schmidt & Wrisberg, 2008, pp. 204–205). The chosen measure is the most suitable 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.

What would be a suitable measure for 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,* and captures 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 (accuracy kept stable), qualifies for skill-learning improvement. 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 $\Delta t$ decreases significantly, $F$ proportionally increases. In a racket-ball system (or bat-ball, hand-ball system etc.), *time* is predetermined 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* (i.e. accuracy kept stable) high forces. Inversely, high performance, i.e. bodies (e.g. tennis balls or hands hitting the clavier in Tchaikovsky's 1st piano concerto 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.

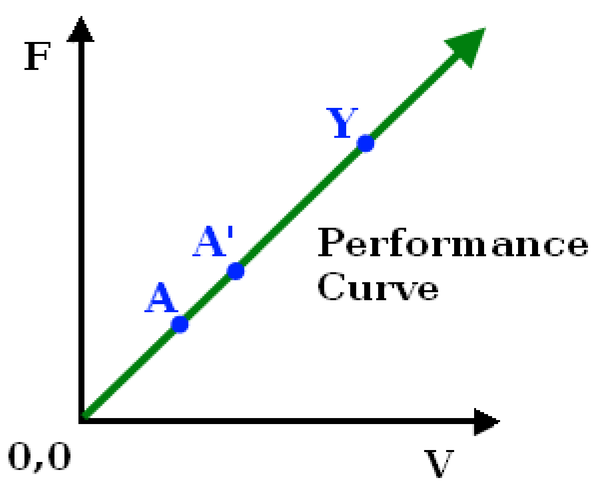


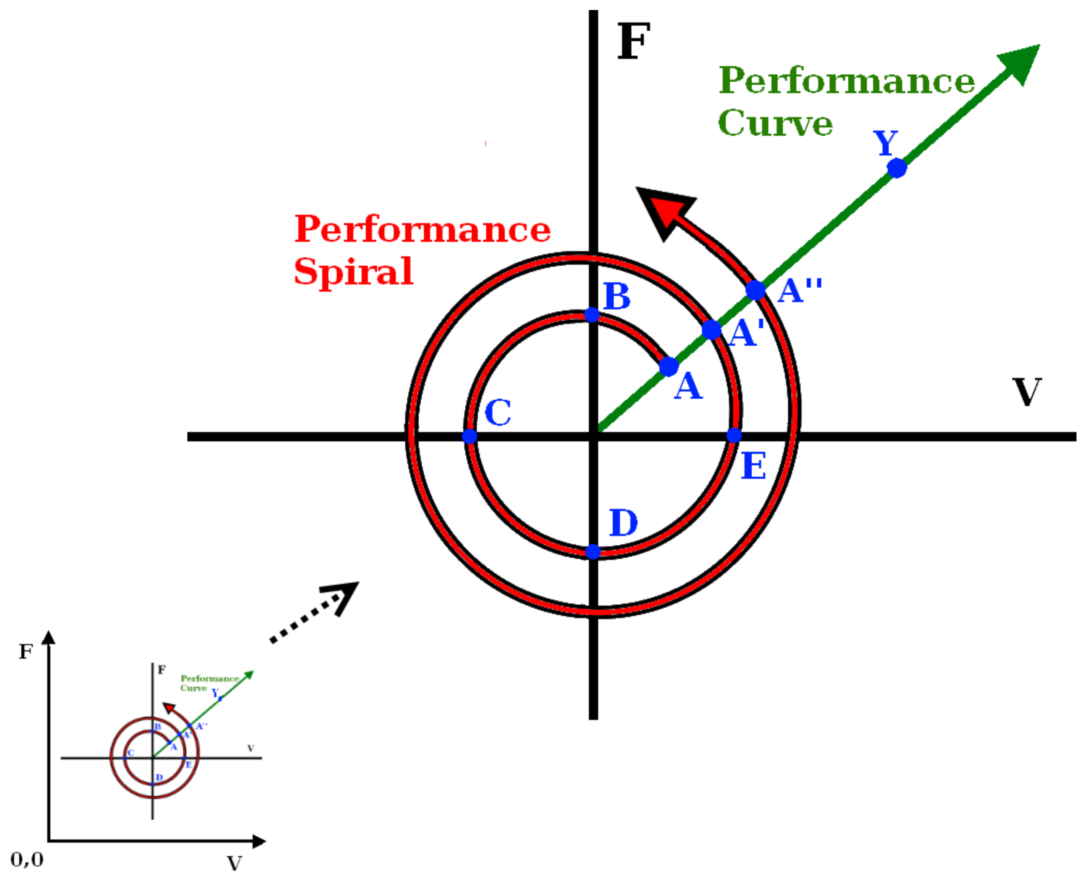

**Figure 1**. The Force-Velocity Performance Curve for a definite accuracy level. A: Initial performance, A': some intermediate performance, Y: Expert performance.

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, 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, improving performance directly is not the optimal way to learn (if it is at all…), and 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; and all these 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 axons, 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. All that is depicted in 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 technique for practicing a motor skill 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*, which (correct technique) is a prerequisite for high performance, and the generalization of the skill gains to higher speeds (attacking attractor notion).

## 1.1 Attacking Attractor

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 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 introduced 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).

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[1] A theory 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.

# 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 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. 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 access 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 wrists 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. Improvement (motor learning) will be regarded any statistically significant improvement in either part of the speed-accuracy graph.

Measurements, using a portable radar-gun (PocketRadar, + / - 2 Km / h in 600 Km / h accuracy – factory specifications) were made before the program (2-months duration) and at the end of the program. To ensure that measurement of 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. 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 highly uncooperative, suspicious, and had poor compliance from the beginning. Characteristically, the study commenced with 18 individuals, seven of them refused to continue as they stated that measurements were time-consuming, or felt exploited (!) when asked to sign the informed consent form.

*2.4 Negative Hypothesis*
$H_o$: There is no difference inside the speed-accuracy level between baseline and final values.

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

## 3 Results

| PS Baseline | | | | |
|---|---|---|---|---|
| *Individual* | *Mean Serve Speed* | *% IN* | *Mean Smash Speed* | *% IN* |
| *7* | 75,8 | 50 | 66,7 | 90 |
| *8* | 90 | 10 | 87,7 | 70 |
| *9* | 100,4 | 50 | 91,6 | 90 |
| *10* | 111 | 10 | 75,1 | 80 |
| *11* | 75,25 | 40 | 77,3 | 60 |
| **Average** | 90,49 | 32 | 79,68 | 78 |

**Table 1**

| Controls Baseline | | | | |
|---|---|---|---|---|
| ***Individual*** | ***Mean Serve Speed*** | ***% IN*** | ***Mean Smash Speed*** | ***% IN*** |
| ***1*** | 109 | 30 | n / a | n / a |
| ***2*** | 100,6 | 40 | 108 | 80 |
| ***3*** | 134,5 | 20 | 116,1 | 80 |
| ***4*** | 138,8 | 50 | 127,3 | 60 |
| ***5*** | 99,8 | 40 | 93,9 | 70 |
| ***6*** | 115,25 | 40 | n / a | n / a |
| **Average** | 116,3 | 36,7 | 111,3 | 72,5 |

**Table 2**

| PS after 4 cycles | | | | |
|---|---|---|---|---|
| ***Individual*** | ***Mean Serve Speed*** | ***% IN*** | ***Mean Smash Speed*** | ***% IN*** |
| ***7*** | 79 | 70 | 83,8 | 100 |
| ***8*** | 90,4 | 70 | 79,1 | 90 |
| ***9*** | 98 | 50 | 110,1 | 100 |
| ***10*** | 115 | 40 | 83,4 | 80 |
| ***11*** | 63,7 | 90 | 66,3 | 70 |
| **Average** | 89,22 | 64 | 84,54 | 88 |

**Table 3**

| Controls After 2 months | | | | |
|---|---|---|---|---|
| ***Individual*** | ***Mean Serve Speed*** | ***% IN*** | ***Mean Smash Speed*** | ***% IN*** |
| ***1*** | 110,6 | 30 | 139,9 | 100 |
| ***2*** | 83 | 40 | 102,4 | 90 |
| ***3*** | 113,5 | 20 | 100,9 | 90 |
| ***4*** | 118 | 30 | 108,3 | 90 |
| ***5*** | 97 | 30 | n / a | n / a |
| ***6*** | n / a | 0 | n / a | n / a |
| **Average** | 104,42 | 25 | 112,875 | 92,5 |

**Table 4**

For tables 1-4: *Mean Serve Speed*: In Km / h; *% IN*: Percentage of balls landing inside the box; *Mean Smash Speed*: In Km / h.

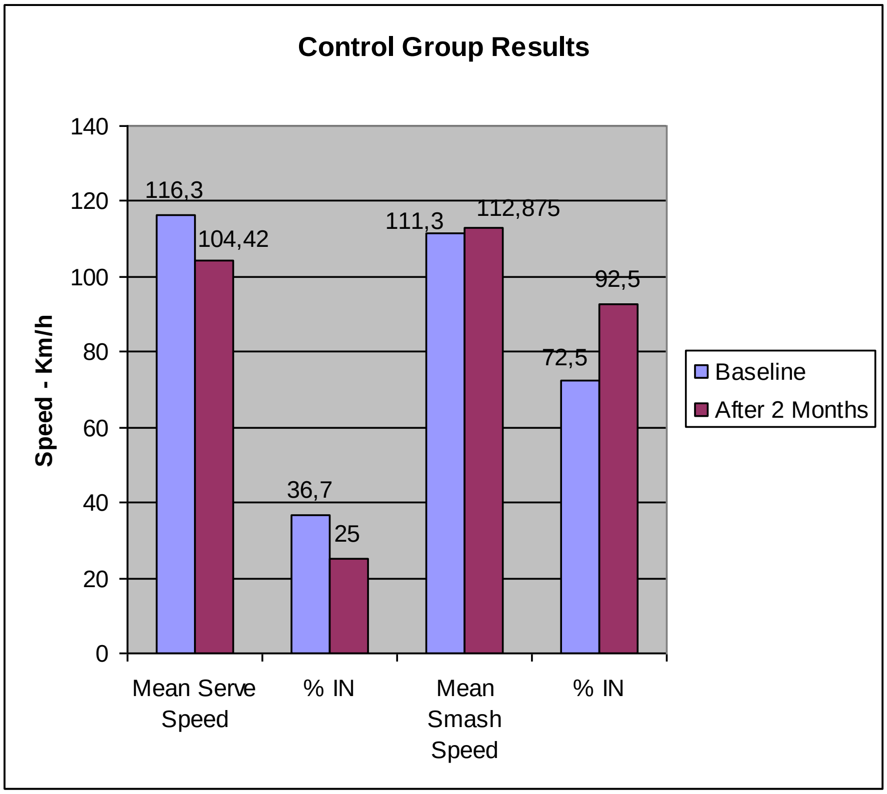


**Figure 3**

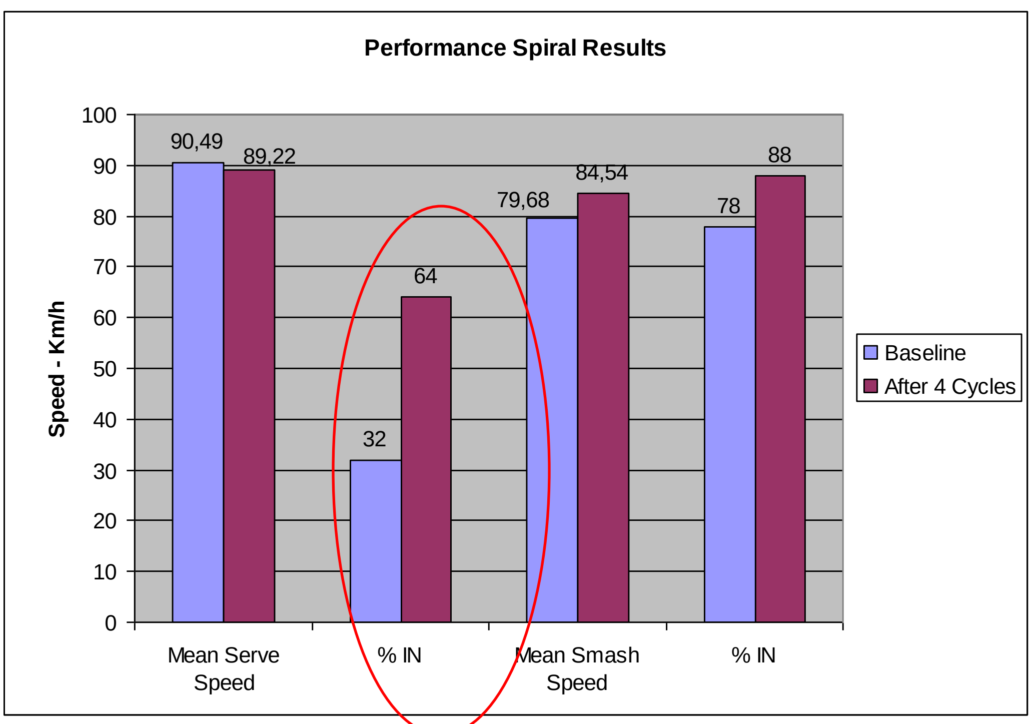


**Figure 4**

| t-Test PS IN%: Two-Sample Assuming Equal Variances | | |
|---|---|---|
| | % IN | % IN |
| Mean | 32 | 64 |
| Variance | 420 | 380 |
| Observations | 5 | 5 |
| Pooled Variance | 400 | |
| Hypothesized Mean Difference | 0 | |
| df | 8 | |
| t | - 2,529822128 | |
| P(T<=t) one-tail | 0,017632602 | |
| t Critical one-tail | 1,859548033 | |
| P(T<=t) two-tail | 0,035265203 | |
| t Critical two-tail | 2,306004133 | |

**Table 5**

# 3 Discussion

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* (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.

The current research protocol involved the tennis serve, not "a wide variety of motor skills". However, as the general ideas from the motor learning and physical training disciplines resulted in the conception of the Performance Spiral model, which had a positive impact in the improvement of the tennis serve (motor learning), there does not seem a reason why one shouldn't expect the benefits to generalize to other motor skills as well; that said, 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 – according to the requirements of the western scientific method.

## 3.1 Motor learning in the current study

Among all the parameters measured, only accuracy improved in a statistically significant way (Table 5). 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 measured. 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.

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.

## 3.2 The room analogy

Motor programs, as a top down notion, methodologically, suffer from the downward-causation problem (Kim, 1998, p. 229). Attractors are insensible to such problems as they are bottom-up mechanisms. However, both refer to, or try to explain, emergent phenomena and really seem to be the two sides of the same coin. The thousands southeast Asian fireflies that synchronize their flashes every night in unison (www.youtube.com / watch?v=IBgq-_NJCl0 accessed 3 / 2 / 2016), are not controlled by some higher mind, a collective soul or a common motor program, but are the result of the "miracle of self-organization" (Strogatz, 2003, p. 34). Such bottom-up phenomena of Bernsteinian synergies manifest themselves *as if there were* a higher motor program. In this respect, downward-causation is not a problem: the epiphenomenon (the spectacle of coordinated fireflies), directly causes to the beholder a sense of awe, regardless of the fact that the spectacle is comprised of individual fireflies and would not be present without them. Individual fireflies are merely a substrate, as is the tennis court – or indeed, at another level, the physical bodies of the players – for the manifestation of a game.

One could go on and discuss the implications of the Performance Spiral without trying to conceive the exact nature of the underlying mechanisms; however, the author believes that the contemporary scientific paradigms should include a holistic, conscious understanding of the phenomena, and not merely regress to cause-effect descriptions from the side of the effect towards the cause (a classic mistake in logic). A synthesis of the Demon-of-the-endpoint (Latash 1998 pp.317-318), and the Chinese Room argument (Kim 1998 p.99) is the one that will be briefly presented here. *The room analogy for non-linear attractor-shifts*.

In a large room there is a ball. The ball, will either remain still, or “obeying” the law of gravity, will minimize its energy by rolling to the lower part of the room (if for example the floor has bumps). The lower point in the room will be the attractor for the ball. However, if a person, instead of a ball, were in the room things would be different. Or not?

The person would move around structures that are useful: sofas, chairs, computers, etc. It is more obvious that in this case, the driving force behind that person’s movements is not a natural law, but a cognitive process. Nevertheless, the physical manifestation of the attractors in the room for the person’s preferences will be things like sofas and tables. One might conceive that some parts of the room attract the person more than others. Thus it is not pre-programmed how to move in the room, but the room structure determines the movement. The person might not move due to the force of gravity, but a structure of the room that somehow, in a Wittgensteinian way resembles the structure of their preferences, move the individual’s body around the room in a more complex, yet almost equally mechanistic way as the gravity moves the ball.

Notwithstanding the physical appearance of the room, the individual might conceive a different structure and rearrange the room. In this sense, a higher cognition now forms the arrangement of the attractors, which continue to exert “mechanistic” influence on the individual with a significant difference: it is the influence that the individual chooses to have. In this way, a hybrid model of higher, top-bottom commands and mechanistic, bottom-up attractors define the behaviour of the individual. The process of room redecoration is what an “attack” to the attractors is: a conscious, deliberate manipulation of the attractors, around which behaviour will be organized. Equally, the conscious organization of behaviour (expressed as skilful performance) will create attractors and will make that level of behaviour a spontaneously coordinated synergy (automatization). This is a clearly non-deterministic model.

The attractors in the room however will not exert the same influence on the individual; individuals will likely be more inclined to be more in some parts of the room than in others. Imagine now that in the room there is a window. This is a powerful attractor, but not powerful enough as there is no furniture in that part of the room. The individual again, decides to rearrange the room to deepen the attractor basin near the window. As furniture is being transferred, there would be a critical number of furniture items (e.g. a sofa, a table, a desk and chairs) that would produce a non-linear attraction-shift to the individual, as now they will be more attracted in that area overwhelmingly more. The individual has not chosen *when* he should be more attracted, this emerged on its own; 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, top-down process as long as the individual insists until another attractor is created. In this analogy, the person is the X, the "ghost in the machine" (Carpenter, 1996, p. 287), consciousness and the external attractor states of the room, are the internal attractor states in the CNS.

## 3.3 Boundary-condition-practice and attractors

According to the results (!), the Performance Spiral led to better motor learning than 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). The structure of the Performance Spiral is such that permits the easy estimation of speed as a learning parameter. 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 deep 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, B., Mayer-Kress, Newell, & Michelbrink, 2009; Wei, Wert, & Körding, 2010). By including slow phases one is able to consciously form an attractor, and by following the four 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, see for example Ericsson, 2006 or for tennis: Papageorgiou, 2014. Slower practice presupposes better understanding of the movement and increased attentional skills and 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). The priming the first phase offers, followed by slow practice may have implications for recidivism issues, following the modern research on reconsolidation (Besnard, Caboche, & Laroche, 2012; Crossley, Ashby, & Maddox, 2012)

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 (see figure 5, from Schöllhorn et al. 2009 p. 330). PS model follows a similar fashion of introducing progressively more and increasingly variant stimuli (there are many ways to practice the parts of the programs, variations of sport loading or overspeed training, utilizing different materials, cognitive strategies, procedures etc.). What has not been tested in this study, but nevertheless seems like a plausible hypothesis, is to practice *at least two* of the parts of the program the same day (always followed by serving normally to test the stability of the technique and induce the *testing effect*). Practicing two parts, instead of just 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).

Moreover, there is one additional benefit. In non-linear systems, such as the ones used in motor skills performance, 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 established attractors. Later, as performers improve, they will increase their speed (following the Performance Spiral model) and by doing so, at some point – in 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.

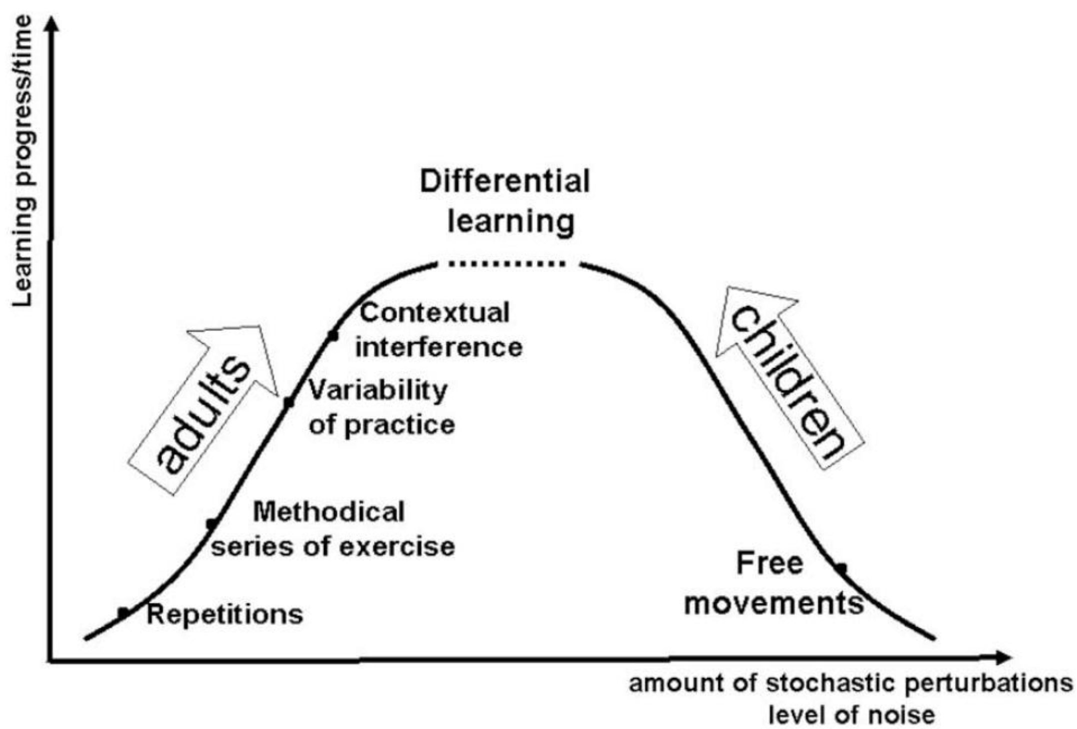


**Figure 5** from Schöllhorn et al. 2009 p.330.

To sum up, slow practice both unfreezes FD's and prevents relapsing to old movement patterns (attractor-states) while it prepares the ground for faster or more resistant performance.

The skill under practice is not randomly chosen; hopefully it has occurred after some form of kinematic analysis of the movement and therefore it represents the preferred mode of movement for the particular activity. Recidivism towards previous attractor states, as well as loss of stability in the presence of perturbations is highly unwelcome. Slow practice, as well as practicing on the boundary of the shift (Flow Practice and Sport Loading) should deepen the attractor basin.

Flow practice in the PS, as is currently utilized by some major school traditions (like weapons training in 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. Almost all activities use equipment; tennis uses rackets, soccer uses a ball and piano playing uses the clavier (F. Liszt and more recently the late great virtuoso G. Cziffra used a flow-practice device for piano playing – www.youtube.com/watch?v=FpWPYa7B7fQ). In the PS, the increase in the level of Flow Practice means the increasing accuracy and duration that 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.

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 adaptation as well.

Finally, 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. 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 PS worth investigating in the future, as empirical evidence show that the parts of PS model are effective in the learning of *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).

Note that performance plateaus are predicted and explained by the competing attractor hypothesis, as the time period when the influence of two attractors is equal. When the preferred attractor basin gets deep enough after deliberate actions, 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).

### 3.4 Schedule and Perceived Competitiveness

While learners found the novel tasks imposed to them by the PS program were demanding to say the least, 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 often: change serving locations, change feedback and rhythm etc. This increased the Contextual Interference of the task. 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

Performance Spiral, and the underlying attacking attractor model present a novel viewpoint in the practice of motor skills and sequences that incorporate elements from vastly different disciplines, yet (PS) is presented in a simple and elegant manner. As a model it consists of the interpretation of axiomatic mathematical systems (Eucledian geometry and set theory) to the training schedules in tennis. The results of this study partly confirm the predictions of the PS, but due to constraints and the preliminary nature of this study, it may better be conceived as a starting point for future designs.

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