Stochastic perturbations in athletic field events enhance skill acquisition

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Chapter six: Athletics Field Events

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Despite the advantages of the constraints-led or cognition-based perspectives on motor learning, we should keep in mind that perspectives provide a constructive though sometimes constrictive basis for the development of models and theories. Theories always suggest models for certain phenomena that are simplified projections of reality (Stachowiak, 1973). Here the constraints-led perspective suggests three abstract factors that form a simplified basis for complex phenomena in the training process, understanding movements in sports in the context of three subsystems: the performer, the task and the environment. Beside the possibility of using these three factors in future as basic variables for models of complex motor control and motor learning theories, another aim of this perspective can be considered as identifying variables that can improve performance by manipulating them. This step is accompanied by specific problems that are implicit in the process of theory- and model-development. In many cases the elements that were excluded in the first step of modeling through simplification are also neglected in the application phase and therefore can produce a new reality that is different from the original one. Specific problems that occur by separating the performer and the environment can be seen e.g. in biomechanics and in the psychology of perception. In biomechanics typically three types of forces are analyzed that are assumed to cause movement. While muscular and gravitational forces can clearly be assigned to either the performer or the environment, the inertial forces can hardly be assigned to one of both. This seems to be even more important when we take into consideration the constant changes of the inertial tensors of all limbs in living systems that are caused by blood flow and breathing. These constant changes take care of involuntary variations in so called movement repetitions, even if not intended by the performer. With respect to perception psychology the separation of performer and environment mirrors similar problems. Dependent on the philosophy one is following the perception process is considered differently: i) as a simple projection of the environment into the perception apparatus of the performer allowing a clear separation of performer and environment, ii) as an active process of the performer that takes only the information out of the environment dependent on his or her past experience, or iii) as dependent on the performers' activities not allowing a separation of the performer and the environment. Similar to the involuntary biomechanical changes of the inertial tensor, the perception process is also changing implicitly all the time due to the previous perception processes. These changes of the performer and the environment or its interactions over time seem to be an essential characteristic of motor control and motor learning especially in sports. On the search for general laws these small but fundamental deviations have been widely neglected so far.

Hence, for the development of a perspective towards a theory we need to specify and quantify the three subsystems, their interactions and their changes over time.
An approach that copes with all three subsystems, their interactions and their quantification in changing situations over time is suggested within the differential training approach.

The basis of the differential training approach

The differential training approach is mainly derived from the observation and essential influence of fluctuations in adaptive systems (Schöner, Haken, & Kelso 1986). This fundamental influence of fluctuations can excellently be observed in the early motor development of children (Thelen & Smith, 1994). During this period children learn more rapidly than throughout their whole life- span, which underlines the importance of the first two to five years of development for learning (ibid.). One fundamental characteristic of learning at this age seems to be a big variety of movements, a small amount of repetitions and only a small tendency to follow instructions, to their adults' regret. In this period repetitions can only be identified on a very coarse level. If analysed in detail each repetition contains a variety of the previous movement even after numerous trials. And these variations are endless during this most effective phase of learning. Typically these variations are rather interpreted as destructive noise or inability to reproduce the same movement twice by adults, rather than as a necessity for effective learning. In contrast the differential training approach claims to take advantage of emphasizing the fluctuations or stochastic perturbations that occur in athletes' movement repetitions in order to provide additional information to the learner, not only from the movement itself, but also by a larger difference between two subsequent movement executions (Schöllhorn, 1999, 2000; Schöllhorn et al., 2006, 2008).
The necessity of differences for cognition in general can be derived from philosophy as well (Derrida, 1967; Heidegger, 1927/2006). From a traditional point of view an increase of fluctuations could be considered as a new term for variable learning. Specifically, the differential training approach distinguishes itself from the variability of practice theory developed by Schmidt (1975) in the application of variability on different variables. While the variability of practice theory suggests to vary the variable parameters in order to stabilise the invariants, the differential training approach pursues variations in the "invariant

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parameters" as well, in order to make the overall movement more stable. The offered variations include variations of joints, movement geometry, velocity, acceleration, time structure and rhythm, variations of 'classical' movement errors, variations of equipment and environment, and combinations of all variations without any movement repetition. In detail the differential training approach adds stochastic perturbations to a to-be-learned movement with the intention to provide a larger space of solution to the athlete, where he or she can react individually and more specifically in a shorter time. In comparison to traditional, more repetition-oriented training, in the differential training approach a higher degree of stability in the to-be-learned movement is achieved by an increased instability during the acquisition process.

In comparison to game sports where ample opportunity for movement variation is provided by a dynamic environment, track and field events attract a special interest because of the rule governed restrictions of movement solution possibilities. In this context the practical application and effectiveness of differential training in comparison to traditional, more repetition oriented approaches, has been studied in several track and field disciplines for different levels and different ages. In this chapter, we discuss some of the results of this program of work and their practical consequences exemplarily for hurdling.

A (track and) field study

In a hurdling differential training-experiment 28 juvenile club athletes (13.2 ± 1.7years) were assigned to a traditional and a differential training group after a 60m hurdle race pretest measured by light barriers. Both groups received specific interventions for 6 weeks with 24 training sessions over-all. Each training session lasted 90 minutes with 30 minutes taken for specific hurdle training. All other parts of the training were equal in both groups.

Training contents of the traditional training group

The traditional group trained according to recommendations of the International Association of Athletics Federations (IAAF) that are mainly oriented on a relatively narrow ideal target movement that is derived from characteristics of world class hurdle sprinters (Jonath, Krempel, Haag, & Müller, 1995). This training is mainly characterized by successively approaching the target movement by means of exercises that display increasing similarity with the to-be-learned movement technique. This approach is supported by the principles of coinciding kinematics and dynamics of the exercise with the target movement (Djatschkow 1973). By experience this results typically in numerous repetitions accompanied by feedback in form of error descriptions and error corrections. In the majority of cases feedback was provided individually for every trial. All performers of this group were informed in advance about the technique by means of photographs and video recordings of world class hurdle sprinters. Furthermore, all error corrections were given according to the IAAF recommended literature that are based on world class athletes as well and therefore are oriented on the same model (Jonath, et al., 1995). A coarse impression of the traditional (T) exercises can be seen in Figure 7 (c.f. Eastern Kentucky University Track and Cross Country Program, n.d.). All exercises T_1 – T_i including the variations ($T_{i\text{-variation}}$) were performed at least 3 times.

- T_1: Walking over 4-6 hurdles with a 6-8 meters distance between the hurdles. During the hurdle step the lead leg starts with lifting up the bend knee (figure 1a). When the thigh is horizontal the knee is extended and the body weight is moved forward in order to cross the hurdle with the lead leg (figure 1b). The trail leg is abducted with parallel external rotation whereby the knee is always higher than the ankle (figure 1c). After passing the hurdle bar the knee of the trail leg is moved towards the breast (figure 1d). When the thigh and calf of the rear leg is in movement direction the foot is moved towards the ground by means of a hip extension (not illustrated).
- $T_{1\text{-Arm}}$: With and without arm movement
- $T_{1\text{-Side}}$: left and right leg

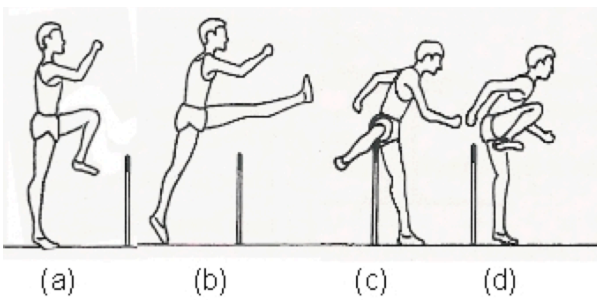

Figure 1 - Traditonal exercise no. 1: 'hurdle marching'. (meaning of letters a-b explained in the text; modified from Haberkorn & Plass, 1992, pp.144 & 147).

- T_2: Comparable to T_1 but the hurdle step is executed by means of a short and flat jump and walking between the hurdles. The jump was instructed with "During the downward movement of the lead leg after the hurdle bar the knee of the trail leg has to be moved up and towards the chest of the same body side (with bend knee) (figure 2b-c).

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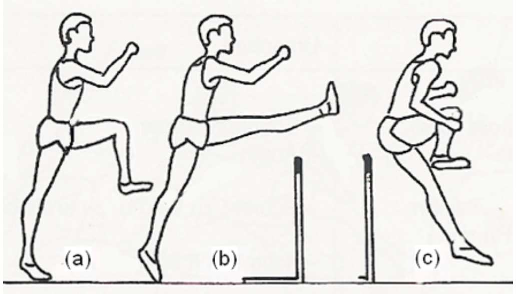

Figure 2 - Traditional exercise no. 2: 'dynamic hurdle marching' (meaning of letters a-c explained in the text; modified from Haberkorn & Plass, 1992, p. 144).

- $T_{2\text{-}velocity}$: with slow running speed at least with 7 steps between the hurdles
- $T_{2\text{-}lead\ leg}$: beside the hurdle, clearing the hurdle only with the lead leg
- $T_{2\text{-}trail\ leg}$: beside the hurdle, clearing the hurdle only with the rear leg
- $T_{2\text{-}combinations}$: Combinations of $T_{2\text{-}velocity}$ and $T_{2\text{-}lead\ leg}$ and $T_{2\text{-}trail\ leg}$ by arranging 6-8 hurdles at the left and right side of a line (for instance track marks). Athletes are running on a line, for instance in the order 'lead leg – trail leg – trail leg – both legs - …'
  a) with 5 steps between the hurdles
  b) with 3 steps between the hurdles

- $T_{2\text{-}supplementary\ exercises}$:
  a) standing in front of the hurdles training only kicking of the leading leg (figure 3)

Figure 3 - Supplementary exercise to exercise no. 2: imitating the action of the lead leg (modified from Haberkorn & Plass, 1992, p. 145).

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b) placing a hurdle around 3-4 feet in front of a wall. Standing beside of the hurdle with the lead foot in nearly 1 feet behind the hurdle. Pushing the trail leg back (figure 4a) and pulling it about the hurdle (figure 4b) towards the chest (figure 4c).

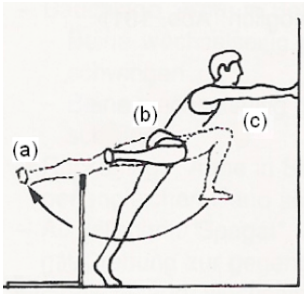

Figure 4 - Supplementary exercises to exercise no. 2: imitating the action of the trail leg (meaning of letters a-c explained in the text; modified from Haberkorn & Plass, 1992, p. 148).

- *T_3*: running completely over the hurdles (figure 5) with
  a) 7step rhythm interval between the hurdles (women around 15.00, men around 17.00m; according to stride length and performance level),
  b) 5-step-rhythm interval between the hurdles (women around 11.00m, men around 13.00m) and
  c) 3-step-rhythm interval between the hurdles (competition distances = target movement)

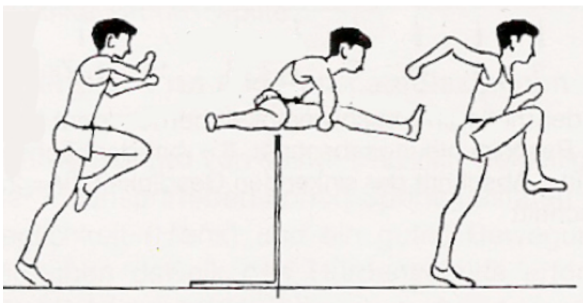

Figure 5 - Clearing the hurdle (modified from Haberkorn & Plass, 1992, p. 134).

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Trainings contents of the differential training group

The training of the differential training group was mainly characterized by no repetition and no error correction in order to generate larger differences between subsequent movements and to allow the athletes to find their own solution for the current movement task. In contrast to the traditional group, the differential training group was oriented on individual and situational solutions that regard possible deviations from an ideal model not as a source of error but rather as necessary fluctuations, providing the basis for adaptations. This is claimed to be advantageous in situations that change every moment in time and is reflected in Bernstein's definition of practice as 'repeating without repetition' (Bernstein, 1967). Instead of mostly identical and stable repetitions every hurdle exercise was combined with a new instruction that always was related to the previous exercise but with an additional task. These additions are termed as stochastic perturbations of the target movement in the classical understanding of ideal, person- and situation-independent solutions (the term 'noise' is avoided because of its common narrow associations with a white noise frequency spectrum that prerequisites equidistant measurement points which cannot be assured in normal training). The differential training approach offers variations in the above described manner in accordance with the specific somato-sensoric and motoric representation of our body in the brain in the form of complex neuronal nets as well as due to their organizing principles (Hubel & Wiesel, 1962; Sheperd, 1980). From every joint neural maps of neurons with this characteristics can be found. However, these maps are supposed to be affected differently in the two described training approaches. In case of T1 in the traditional approach the movement is just repeated several times with some instructive error corrections. In the differential training approach already at the second hurdle a modification of the first hurdles task has to be performed. This modification can be e.g. a change in the arm position (figure 6a), in the knee angle (figure 6b) or the position of the trunk (figure 6c). At the third hurdle this modification can be a more extended elbow angle, at the fourth hurdle it can be a modification of the hip flexion velocity and so on.

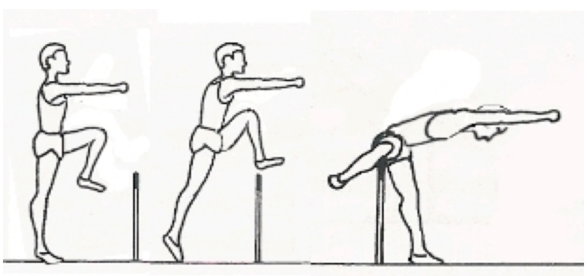

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Figure 6 – Example for a modification of traditional training exercises in the differential training approach by changing the geometry of the movement (modified from Haberkorn & Plass, 1992, p. 144).

While the traditional approach follows consequently the first column downward in Figure 7 with several mostly identical repetitions, the differential training approach always meanders along the lines with constantly modifying the original traditional exercise. Thereby the modifications can vary every time in each joint and in each joint related variable. Once the rhythm is modified, it can be related to a single joint as well as to several joints where a joint movement can be slow-fast-slow, for example. If we do not limit these variations to the hurdle step but also open it to the steps between the hurdles an additional amount of variations will occur. Obviously these variations differ enormously from the variations that are suggested by the variability-of-practice approach. The differential training approach also differs from the contextual interference approach (Shea & Morgan, 1979) due to the number of variations. While in the contextual interference approach it is switched between two to four ideal target patterns in most cases, in the differential training approach no ideal target pattern exists and therefore an endless number of variations is available.

exercise	variations in movement execution																							
	ankle (l/r)				knee (l/r)				hip (l/r)				shoulder (l/r)				elbow (l/r)				hand (l/r)			
	φ	ω	α	ρ	φ	ω	α	ρ	φ	ω	α	ρ	φ	ω	α	ρ	φ	ω	α	ρ	φ	ω	α	ρ
T_1																								
T_2																								

FIGURE 7 - Suggestions for stochastic perturbations that are oriented on traditional methodical series of exercise. Legend: φ: joint angle; ω:joint angular velocity; α: joint angular acceleration; ρ: rhythm; Ti: traditional exercise

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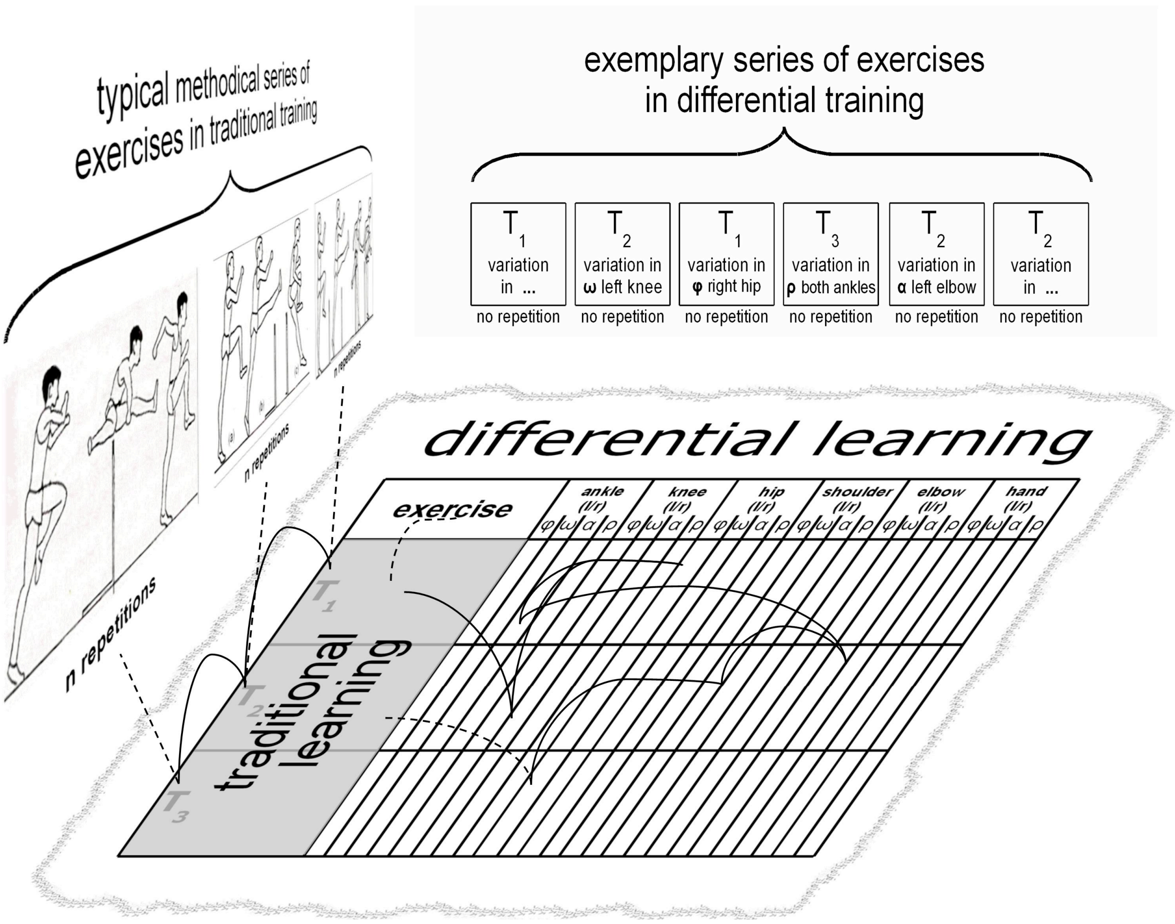

Figure 8 - Suggestion for a systematic approach for stochastic perturbations in differential training using traditional methodical series of exercise (T_i) and possible changes in joint angles (φ), joint angular velocity (ω), joint angular acceleration (α) and internal rhythm (ρ).

Results

In order to ensure that results are not caused by enormous changes in performance of single individuals, the results are compared qualitatively in advance (Figure 9). When we compare the individual performances during the pre- and the post-test of the traditional training group and the differential training group pairwise, a clear advantage for the differential training group is evident. Every individual of the differential training group has at least one partner in the traditional training group that increased less.

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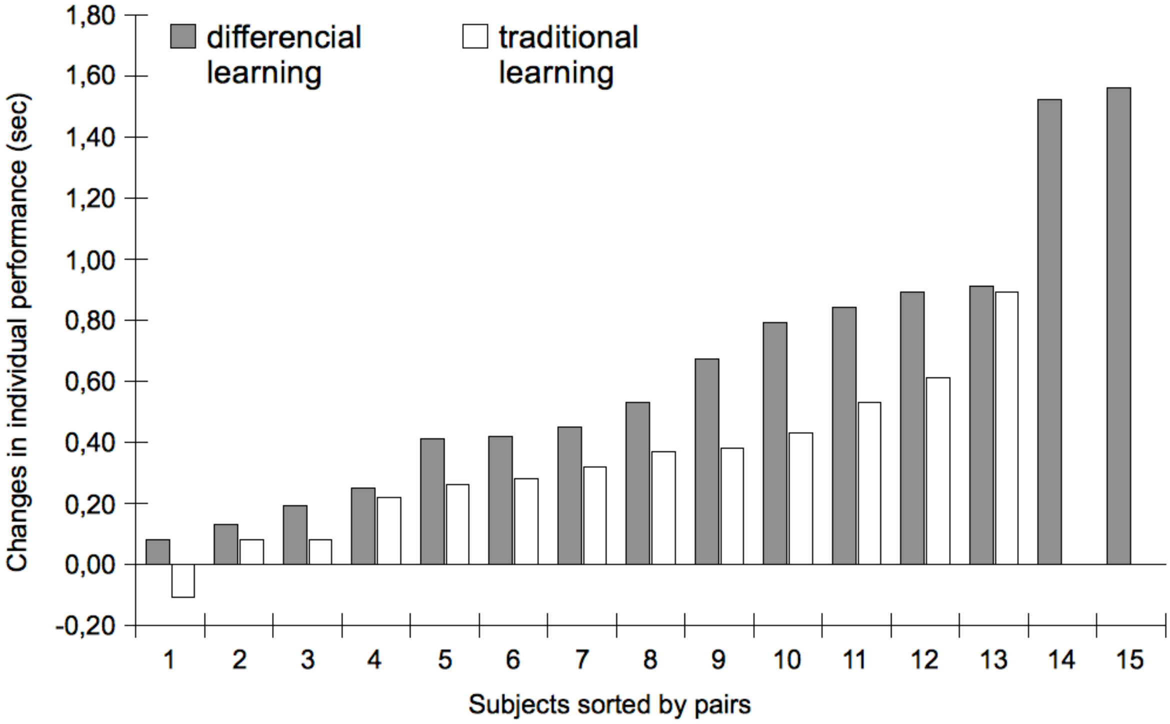

Figure 9 - Changes of individual performances over 60m sprint hurdle race of traditional learning and differential learning group sorted by pairs

Analysis of group means showed no significant differences for both groups during the pretest in which the traditional training group ran 60mH on average in 11.76s and the differential training group in 11.70s. After six weeks of intervention both groups improved their performance significantly by means of 0.33s (traditional group) and 0.64s (differential group) whereby the differential group improved its performance significantly more than the traditional group (p=0.034). Figure 10 illustrates the group means.

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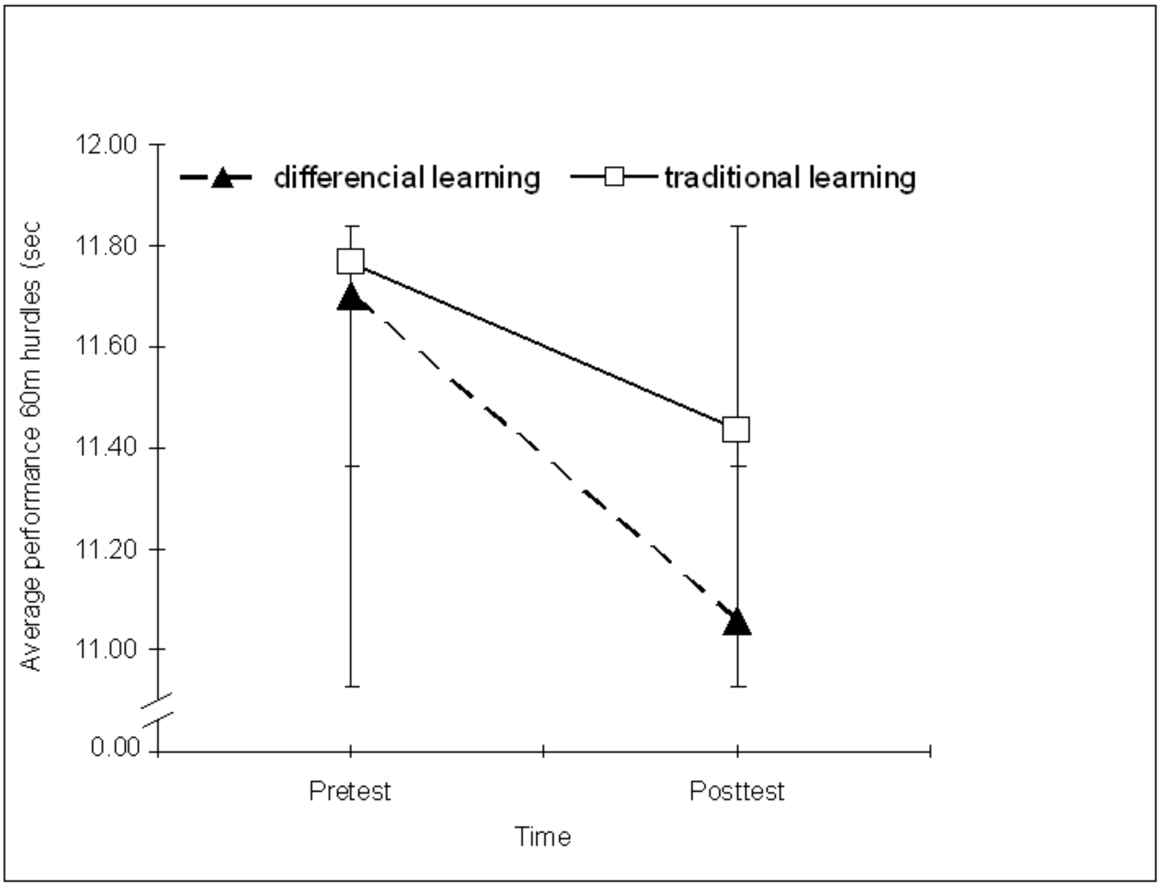

Figure 10 - Average group performances for 60m sprint hurdle race of the traditional and differential learning group during the pre and the post-test.

Conclusions and outlook

In the traditional understanding of skill acquisition by means of drills in order to generate automated motor programs, the differential training approach at first glance seems to be counter intuitive. Most intriguingly, members of the differential training group improved their hurdle sprint ability significantly more than the traditional drill oriented group despite or rather because of the training of errors. In accordance with the predictions made in the historical beginning of the theory of differential training (Schöllhorn, 1999) the training with stochastic perturbations seems to initiate a type of self organizing optimization towards individual and situational optimization. Overall the results verify previous findings in shot put (Beckmann & Schöllhorn, 2003), soccer (Schöllhorn, et al., 2006), tennis (Humpert & Schöllhorn, 2006), and Handball (Wagner & Müller, 2008) where similar advantages of the differential training approach could be identified not only during the acquisition phase but also in the subsequent retention phase.

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Advantages of the differential training approach can be explained by the additional assumption of system changes by itself on different time scales (Schöllhorn, Mayer-Kress, Newell, & Michelbrink, 2008). In traditional approaches task as well as athlete are assumed as constant and stable systems while variations in the environment are assumed to cause necessary adaptations. In contrast, the differential training approach assumes the athlete as a continuously changing subsystem by itself. On the basis of this assumption a once chosen stable task has to be adapted on different time scales to a changed subsystem "athlete" and to a changed subsystem "environment" or to changes of their interactions.

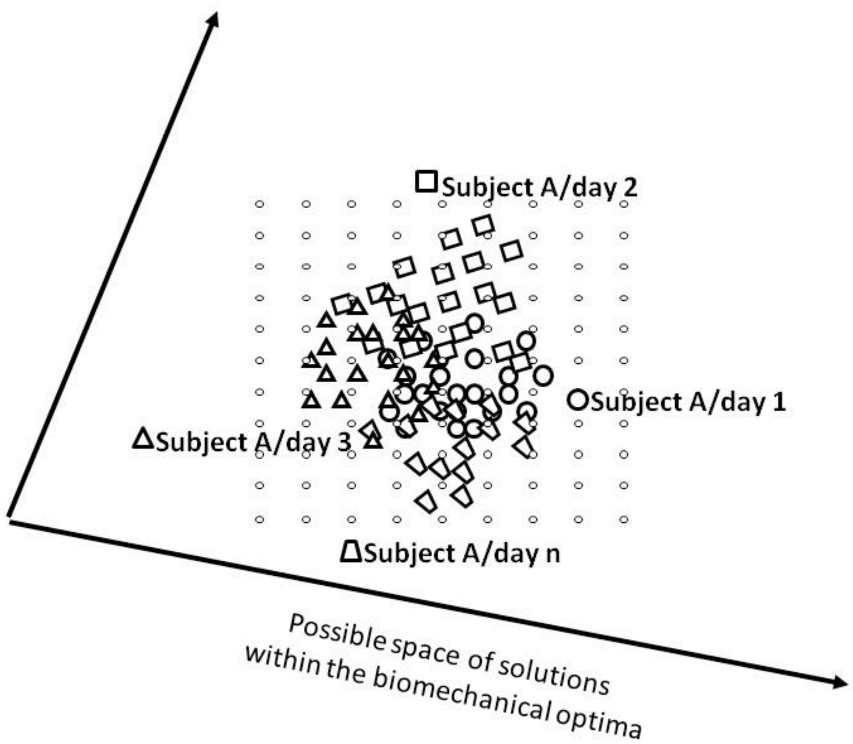

Figure 11 – Schematic depiction of several training sessions of a single subject in discus throw.

Support for this assumption is provided by investigations on the stability/variability of several training sequences (Bauer & Schöllhorn, 1997). The analysis of several throws of world class discus athletes over a period of one year not only revealed individual throwing styles but also day dependent throwing patterns that where more similar within one day than between different days. In figure 11 an explanatory schema for several training sessions of a single subject is displayed. Obviously, no throwing pattern within any training session is identical and all throwing patterns of a single training session cover a different area within the possible space of biomechanical solutions that only overlap in small areas. Most

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interestingly, although there is only a limited area of overlapping the covered space is continuously forming the characteristics of the throwing patterns of each individual, which rarely overlap with throwing patterns of other individuals. However, the continuously growing area corresponds to a continuously changing subsystem “athlete” and provides also an explanation for phenomena that occur after a longer break. During such a break the changes of the subsystem can be expected to be larger and probably lead to a movement pattern that is outside the area that has been covered from throws in previous training sessions. This may then lead to poorer performance. In a traditional point of view the space of possible solutions will be covered slowly by numerous repetitions and error corrections. Alternatively, the differential training approach, in accordance with the logics of artificial neural nets (Herz, Krogh, & Palmer, 1991), covers the whole possible space of solutions from the beginning with a coarse meshed net, relying on the system’s ability to be able to interpolate well within the nodes of the net. Evidence for such an ability in humans is provided by our visual system that constantly interpolates over our blind spot in which the visual nerve departs the eye towards the brain. Beside the explanation of several other phenomena one advantage of this model-assumption is a more effective organization of the learning process by means of a smaller number of movement executions.

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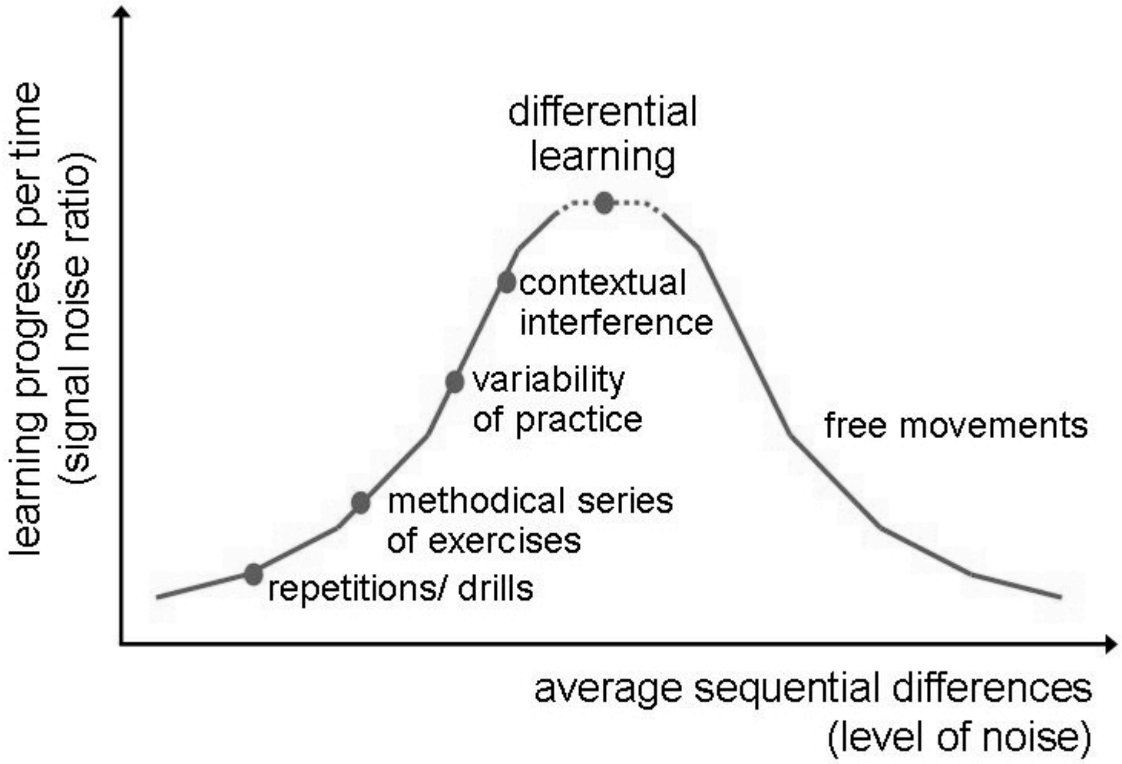

Figure 12 – A framework for different motor learning approaches (Schöllhorn, Mayer-Kress, Newell, & Michelbrink, 2008).

Keeping in mind the above described logics of artificial neural nets, another advantage can be seen in the assignment of other movement learning approaches to a more generalized learning model. In this model all motor learning theories can be considered as the application of nets with different mesh size or as applications of a different amount of noise (Schöllhorn, Mayer-Kress, Newell, & Michelbrink, 2008). In consequence, finding the optimum learning approach for an individual athlete corresponds to finding the optimum amount of stochastic perturbations for each individual in each situation. In these terms the repetition approach (Gentile, 1972) is associated with a small amount of noise but also corresponds with a small learning rate (learning progress/time). The methodical rows of exercise approach (Gaulhofer & Streicher 1924), the variability of practice approach (Schmidt, 1975) and the contextual interference approach (Shea & Morgan, 1979) display an increasing amount of noise with increasing learning rates in this order. Figure 12 shows schematically this assumed influence of subsequent exercise differences on the learning rate. From the figure information can be derived on the change of noise dependent on the situational noise identification. When

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athletes, mostly beginners or children, show a big variability in their movement repetitions it is traditionally recommended to reduce the 'noise' in the training, whereas in more advanced training (when the movement repetitions become more stable) an increase of the variations is demanded in order to come closer to the optimum 'noise' of the training contents. With respect to the learning rate the most effective amount of stochastic perturbations seems to be provided by the differential training approach (Schöllhorn, 1999, 2000) while a further increase would result in a decrease of the learning rate. A further decrease can be associated e.g. with the additional training of other sports disciplines, e.g. if a hurdle sprinter from track and field is training basketball or swimming additionally. Maybe this additional training will provide a broader basis for future development but with respect to the hurdle technique no essential support is expected. The reason for no single but rather a blurred maximum in figure 11 is related to the fact that not only were individual movement patterns identified in previous studies, but also the individual's level of fatigue (Jäger, et al., 2003), certain states of emotions and even the type of music an athlete is listening to during a movement (Janssen et al., 2008).

For track and field practice in general the experiments and the corresponding theory suggests a questioning of the traditional repetition oriented approaches. It questions the role of ideal person independent and time stable movement patterns. Alternatively, the differential training approach suggests increasing the fluctuations in order to achieve more individual and more stable solutions. In hurdle sprint this is accompanied with additional stochastic perturbations. In a traditional point of view these perturbations correspond to the execution of errors that counter intuitively lead to an increase of performance during the acquisition phase. Verified by several other experiments like in shot put (Beckmann & Schöllhorn, 2003) the same intervention is accompanied with further advantages during the retention phase. Obviously, the differential training approach in track and field supports the exploratory character of a larger space of solutions that does not reduce the variations with learning progress but shifts the variations from more kinematic to dynamic and rhythmic variations.

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