

## Short Communication

# Metastable Strength Performance-A Complementary View to Training and Assessment

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### Abstract

Many open motor skills, for example in team sports and combat sports, must be executed under mild to severe conditions of instability. Therefore, over the past two decades, coaching professionals and athletes have shown increasing interest in training routines to enhance the physical prerequisites for strength performance in such situations. Exercise scientists have identified instability strength training as a possible means to improve strength performance with a special emphasis on the core muscles. In this short communication, more specifically, we conclude that the stabilizer muscles should be a main target of instability strength research. However, we consider instability to be an inappropriate term to characterize mild to moderate equilibrium disturbances during competition and exercise. Instead, metastable states of equilibrium appear to better suit the conditions of strength performance on slippery surfaces, waves, during gusts of wind or tackling opponents for example. On a general scale, metastability is a property of dynamic systems found in thermodynamics, financial markets, climatology, and social groups for instance. A metastable state of equilibrium is not a true equilibrium but rather located on a continuum between a stable and an unstable state of equilibrium. It is characterized by inherent mechanisms that compensate for mild to moderate disturbances while leaving the metastable state of equilibrium unchanged. Only large disturbances will force metastability towards an unstable equilibrium that possibly changes in to a new state of equilibrium. Hence, we argue that metastability can be applied to issues regarding the biomechanical equilibrium conditions during perturbed strength performance as well. As a consequence, we propose that the metastability concept should be considered as a key characteristic of performance, exercise and corresponding assessment procedures.

### Introduction

On many occasions in sports, athletes, when executing motor skills, can experience balance disturbances such as when tackling opponents in team sports and combat sports, cutting maneuvers, slippery turf, strong winds or waves, for example when surfing on a board, or when skiing moguls in alpine skiing. During the past two decades, training methods have evolved in this regard and have been denoted as Instability strength or Resistance Training (IRT) [1-5]. For this purpose, exercises have been suggested to lift loads or perform jumps on unstable platforms such as wobble boards, inflatable rubber discs, or bosu balls [1,6]. In addition, more recently, muscle activities have been examined during instability lifting exercises with unstable loads (e.g., weights suspended from a parallel bar by an elastic band [7] or plastic pipes with liquids [8]). Unfortunately, so far, only weak evidence has been provided for any clear superiority of IRT over traditional resistance

training [5]. The reasons for this uncertainty appear to be related to a lack of specific knowledge on the neuromuscular activation in the primary movers and the stabilizer muscles during instability exercises and corresponding neuromuscular adaptations (a general misconception of the instability notion and a possible mismatch of training and testing procedures). Therefore, it is the aim of this short communication to analyze existing literature in this regard, to have a closer look at issues related to instability strength exercises, to suggest an alternative approach to conceptualize human motor behavior during ongoing variations in mechanical equilibrium, and to derive some complementary conclusions on training and assessment.

### Instability Strength Exercises

In the past, authors have attributed the benefits of IRT to strengthening of the core [2,9,10] as a key factor in athletic performance and injury prevention [6,11-15]. In particular, it has been

the core muscles with stabilizing and force transducing functions within kinetic chains, for example during throws and jumps, which have been considered [10,13]. However, little attention has been paid to the distinction between primary movers and stabilizer muscles in this regard. From a theoretical view point, strength training effects have been traditionally categorized by either muscle hypertrophy or improved neuromuscular activation [16,17]. Depending on their line of action in respect to the overall movement direction and on the co11 activation of their antagonists, activated muscles may be roughly categorized as stabilizers or primary movers. Whilst, specific results on any muscle hypertrophy effects of IRT in the stabilizers and the primary movers are amiss [5] neural adaptations through IRT appear to be more plausible for both categories. For example, muscle activation studies for the primary movers (e.g., m. pectoralis m. or m. triceps br.) during barbell chest presses on stable versus unstable support platforms showed either no differences (e.g., swiss balls vs. bench) [18-21] or lower degrees of muscle activation [8,22,23]. Similar results were found in the leg extensor muscles (e.g., m. quadriceps fem.) during squatting exercises or plyometric jumps on unstable platform supports (e.g., wobble boards or inflatable dyna discs). While some researchers found lower muscle activation in the primary movers during unstable exercises [24], others did not find any differences [7,21,25,26]. Reductions in the muscle activation levels for the leg extensors were also reported for vertical jumps and drop jumps on unstable vs. stable platform supports[27].

In contrast, stabilizer muscles (e.g., m. rectus abdominis, m. obliquus externus abdominis, m. erector spinae, or m. soleus) showed higher activation levels during unstable as compared to stable exercise modes in both barbell chest press exercises [8,20,22,23,28-30] and squatting tasks [7,21,24], and for postural balance tasks [31]. In addition, larger muscle activation levels in the primary movers were also reported for instability exercises with dumbbells as compared to barbell exercises, with the latter less demanding in regards to postural stability [32].

In summary, studies in the literature show a smaller, or at best similar, neuromuscular activation in the primary movers for chest presses and squatting exercises on unstable as compared to stable platforms. The opposite is true for the stabilizer muscles. Here, all in all, larger muscle activities are detected when exercising under unstable vs. stable conditions. In this respect, it does not matter whether unstable platforms or unstable loads are used [7,8].

Therefore, IRT appears to provide a better adaptation stimulus for the stabilizer muscles than for the primary movers [33]. In addition, instability exercises appear to be better suited for a weight loss program as the total energy cost was found to be significantly larger when exercising on unstable platforms [34]. Con-

sequently, IRT may be considered as a useful tool to promote stabilizer strength. Furthermore, misconceptions should be eliminated such that IRT is an additional rather than a competing alternative to traditional strength training regimens [19,20,35-37]. In turn, IRT does not provide a suitable muscle adaptation stimulus for the primary movers. Instead, stable exercise conditions with maximal loads are required to provide changes in the neuromuscular activation pattern of the primary movers [16,17].

A further point deserves notice. In the past, most studies on instability strength performance have used bench press exercises when lying prone on swiss balls, or squatting exercises on wobble boards or dyna discs, while aiming for a strengthening of the core (see reviews by [1,2,5,38]). Here, primary movers of the trunk and the leg muscles and trunk stabilizers were analyzed. However, studies on the hip stabilizers (e.g., adductor and abductor

muscles) are hardly known in the literature on IRT. In particular, it is unclear whether and how the hip stabilizer muscles will change their activation pattern from stable to unstable support conditions during leg extension tasks. However, hip stabilizer strength and adductor [9] to-abductor strength ratios have been identified as suitable indicators for the risk of groin injuries, for example, in soccer players and hockey players [39-46]. As a conclusion, it is therefore important to relate IRT not only to the anatomical core [2] but to stabilizer muscles in general.

### **A Metastability Approach to Human Motor Behavior**

So far, the IRT has been suggested to prepare the athlete for balance disturbances encountered during competition. However, instability may not be an appropriate term to capture ongoing variations in the body equilibrium. Equilibrium typically describes the state of a body that is not changing its speed or direction when all forces acting on it are completely balanced. Traditionally, three typical states of equilibrium are distinguished by their responsive behavior to perturbations [47]. When in stable equilibrium, systems will return to their original location if displaced. In turn, systems are in a state of unstable equilibrium when they do not return to their original location contingent to even the slightest displacements but instead pass into new states of equilibrium. Objects showing neither tendency to move back or away from their initial states are referred to as in a neutral state of equilibrium. These conditions of true equilibrium are typical for rigid bodies but rarely found in living bodies. Here, variable muscular activity at rest and during motion, aside from ongoing mechanics of vital processes such as breathing, cardio-vascular functioning, and digestion, constrain true states of equilibrium. Therefore, a stable state of biomechanical equilibrium must be considered a virtual target condition of the mover attempting to control for body posture during ongoing changes of static and dynamic environmental task constraints. Rather, the maintenance or control of a given state

of motion is typically achieved in a metastable state of equilibrium when aiming for, but rarely reaching, stable equilibrium.

A metastable state is not a true state of equilibrium but an intermediate to the stable and unstable states. For example, the stock market and its indices is not greatly disturbed by single buys or sales. However, for example, near the end of a positive trend, the participants watching the market may begin to sense that the market is approaching an unstable state of equilibrium. A butterfly effect may arise whereby a few traders sell, pushing the market imperceptibly lower. As a consequence, more traders, sensing this microscopic downturn, may decide to sell. An avalanche of sales may evolve with all traders hoping to protect their profits by selling before the market drops. Such processes have been conceptualized by specific financial market models [48] based on general theories of metastability in non-linear dynamic systems [49].

Dynamic systems, in general, comprise of inherent mechanisms including processes of self-organization and self-organized criticality which compensate for small disturbances to maintain a state of metastability between stable and unstable states of equilibrium. While stable, unstable, and neutral states of equilibrium are traditionally referred to rigid bodies with all acting influences compensated by others, metastable states of equilibrium are typically found in dynamic systems such as in thermodynamics [50], financial markets [51], protein folding [52], climatology [53], fluid physics [54], digital systems [55], electrical circuits [56], neuroscience [57], brain dynamics [58], cognitive functioning [59], and social group dynamics [60]. In the past decade, metastability has already become an issue in human motor coordination to conceptually describe the non-linear dynamics of adaptive behavior in the body when aiming for a state of relative coordination within changing performance environments [61,62]. This work is closely connected to the understanding of human

coordination dynamics [63]. In this regard, methodological approaches have evolved providing experimental evidence on metastable system dynamics for a punching task in boxing [64], a batting task in cricket [65], in postural dynamics [66], and to capture interrelations in social coordination, tactical solutions and learning [67]. Although these studies have predominantly focused on the coordination transitions between preferred movements while looking for attractor states and transition within the perceptual motor workspace, corresponding approaches can be found for the issue of stability, variability and mechanical equilibrium in human locomotor behavior as well. For example, England and Granata [68] have provided results on the stability and kinematic variability of human gait using the Lyapunov stability model. In a broader sense, humans are constantly in a state of metastability. When standing erect, they continuously show swaying movements of the center of gravity which are easily being compensated for by

predominantly unconscious motor control mechanisms. Here, the movers will perceive their state of motion as stable, while their state of equilibrium is metastable. For large challenges of balance, the movers may perceive their state of motion to be unstable while moving the present state of metastable equilibrium towards unstable states of equilibrium. For example, during athletic training on an instability device (e.g., wobble boards, exercise balls) or during running on uneven surfaces, small to moderate swaying would be compensated for in order to maintain a metastable state of equilibrium. Only large disturbances will force the athlete's center of mass projection to travel to and beyond the boundaries of the base of support such that he will leave the metastable state of equilibrium, approach an unstable equilibrium, and eventually drop from the device. To maintain the metastable state of equilibrium, a variety of sensory systems may be employed to constantly monitor the metastable state and correct internal and external perturbations through a number of actuators through the neuromuscular system [69]. For example, postural sway, which can be affected by internal perturbations such as changes in thoracic volume with ventilation [70], is counteracted by plantar flexor contractions that can occur on average two to three times per second [71]. Subcortical areas such as the cerebellum, predict and execute the plantar flexor contraction forces necessary to correct these perturbations [72]. For the locomotor system, mechanical models have been established to show the shock absorbing and self-stabilizing qualities in the architecture of muscles, tendons, and ligaments [73]. Hence, the human body must be conceptualized as a dynamic system with its inherent mechanisms to maintain metastable states of equilibrium. These mechanisms refer to interactions of voluntary control, interconnected neural circuits and reflex loops on one side [74], and mechanical properties encompassing equilibrium point control, and elasticity of muscles, tendon and ligaments on the other side [73]. Therefore, metastability would more properly denote the situational constraints of human motor performance in sports as compared to the traditional states of equilibrium with reference to rigid bodies highlighted in traditional textbooks of sport biomechanics and movement science [75,76]. Unfortunately, in the past, an equivocal use of terms and expressions related to equilibrium, stability, and balance issues in sports has obscured a clear communication of metastability in human motion, not only in scientific discussions but in everyday language as well. In this regard, Kibele and co-workers [77] have suggested a clarification in the proper use of corresponding terms related to human motor performance.

## Conclusions

The above outline of the metastability concept to human motor performance has highlighted the specific benefits of IRT to improve stabilizer strength including sensorimotor interaction.

However, at this point, it remains unclear whether IRT or specific strength training for the stabilizer muscles under stable conditions should be favored. More research is needed in this respect. According to the principle of exercise-type specificity [78,79], however, we may speculate that the overall muscle activation pattern in IRT including stabilizers and primary movers to be closer to the goal movement during competition than an isolated strengthening task for the stabilizers only. Furthermore, metastability should be viewed as a general state in human motor performance rather than an exception of it. In this respect, testing for metastable strength performance might pose a new challenge for performance analysis in sports. So far, biomechanical tests on stable surfaces have been predominantly used to analyze effects of IRT interventions [35]. However, it appears plausible that stable execution conditions are inadequate, as compared to unstable testing, to capture the specific adaptation effects of strength exercises on unstable surfaces. In this regard, a study by Kibele and Behm [80] showed superior task performance in a test with high demands for locomotor stability (one24 legged hopping test) of subjects who previously trained under unstable as compared to stable execution conditions, while stable tests did not provide differences between the groups. Therefore, comparable tests on stable versus unstable support bases are needed to examine strength and agility under opposing degrees of metastability. From the above, we hypothesize that benefits of IRT versus traditional resistance training regimens will be identified in unstable rather than in stable strength testing conditions. In this respect, stabilizer strength might prove to be a yet unattended athletic ability in sports.

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