Moving Minds

Crossing Boundaries in Sport Science

6th International Congress on Complex Systems in Sports

15th - 17th September, 2021

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BOOK OF ABSTRACT

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WELCOME NOTES

Dear readers,

this proceedings volume summarizes the contributions of the 6th International Congress on Complex Systems in Sport, which was held virtually from Sep. 15th – 17th, 2021 hosted by the Institute of Sport Science at the Johannes Gutenberg-University Mainz, Germany.

During three days in September 2021 not only scientists of the “complex systems in sports” research network from Spain, Lithuania, Macedonia, Portugal, Germany, Netherlands, and the US, but also guests from all over the world came virtually together to address current challenges and advances in the field of sport science. Bringing together scientists from various countries and disciplines (e.g. sports, medicine, physiotherapy, psychology, physiology and performing arts), the ICCSS did strive for the goals which the hosting Johannes Gutenberg University (JGU) sets itself: to promote and implement innovative ideas, to use knowledge to improve people's living conditions, to move them, and to cross borders. It is called the “Gutenberg Spirit: Moving Minds, Crossing Boundaries”, which was also the motto of this year’s ICCSS.

This year's ICCSS addressed how emerging approaches in theory and practice can be used in a meaningful way to better understand athletes, to contribute to efficient and effective training, and to assess the added value of new analytical approaches. This year’s motto also implied facing upcoming challenges and possibilities due to technological progress. The 6th ICCSS provided a forum to discuss cutting-edge 21st century analyses, technologies, and advances such as artificial intelligence and robots, augmented reality, and ubiquitous computing technologies, while at the same time connecting them to different pedagogical approaches, types of learning settings, and application domains that can benefit from such technologies.

We wish you numerous inspirations on the following pages that will give an impression of the diversity and originality of the congress contributions and serve to expand the knowledge of complex systems in sports.

Sincerely,

Wolfgang I. Schöllhorn
University-Professor for Training Science and Movement Science
Conference President

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INVITED SYMPOSIA

The Five W of Movement Monitoring in Sports

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Several new types of wearable sensors are used nowadays within biomechanics to measure motion and inertial forces during sport related movements (Aroganam et al., 2019). Measurement units based on inertia (Inertial Measurement Units [IMUs]) often used in association with magnetic field sensors (MIMUs) are currently the most employed in several sports applications in performance enhancement (Camomilla et al., 2018) and injury risk mitigation (Sheerin et al., 2019). These new technologies allow for data collection outside of a lab setting granting for ecological validity, while having a limited cost and improved portability with respect to lab-based equipment (Macadam et al., 2020). Along with their easiness of use, these characteristics are at the basis of a huge positive potential which is however paralleled by a potential for unsuitable use. A full awareness of both sides of the coin is at the foundation of bridging the disconnect between this capability and actionable insights to sport practitioners (Huges et al., 2021).

Within this framework, this lecture will provide an overview on:

i-ii. why and where measuring sport movement to monitor performance (technique analysis, activity classification, motor capacity and physical demands assessment) and deal with preventing, assessing and informing the recovery from sport-related injury;

iii. what variables can reliably be measured by MIMUs, highlighting key factors for best practice and details on which sport assessments are more prone to negative effects of sensors limits and error sources;

iv-v. when and who should monitor it;

vi. how to build these data into actionable insights, also in the light of the recent increase of using artificial intelligence to this aim.

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Machine Learning Approaches for Analyzing Runners Data

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Traditionally, analyzing movement parameters of athletes has been done by collecting data using expensive sensor systems in controlled laboratory conditions. The advent of inexpensive, portable sensors such as inertial measurement units (IMUs) has enabled the ability to collect (large) datasets "in the wild." The question is to what extent is it possible to perform analysis similar to those done in the lab in real-world outdoor settings. Machine learning is one of the key techniques for exploiting the data collected by these cheaper sensors. In this talk, I will focus on our line work on applying machine learning to sensor data collected from runners [1-3]. Unfortunately, working with such data is very challenging from a machine learning perspective. Specifically, I will highlight three key challenges. First, such data needs extensive preprocessing and manipulation (e.g., feature construction) in order to convert it into a format that amenable for standard learners. Second, consideration must be given to how to account for the individual characteristics of the athletes. Third, there a number of difficult methodological aspects that must be considered when evaluating learned models. I will sketch how we tackled these challenges and provided some the key lessons that we have learned. Finally, I will briefly mention how some of our technology is actively being used in practice by elite athletes.

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Technique Analysis in Alpine Skiing Based on Principal Movements Calculated from Wearable Sensor Data

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As athletes acquire and improve skill in their sport, they usually converge to specific, individual movement patterns, often called the individual technique of an athlete. Unfortunately, comparing techniques between athletes is challenging due to the multidimensionality of the human movement system and due to anthropometric differences between athletes. One approach to overcome these challenges is to calculate Principal Movements (PMs) from a group of athletes (Federolf, 2016). The PMs are obtained through a principal component analysis applied to normalized kinematic data (Haid et al., 2019). Projecting kinematic data of different athletes onto the PMs provides scales, through which techniques can be quantitatively compared (Federolf et al., 2013; Gløersen et al. 2018; Werner et al., 2020).

The goal of this project was to develop a skiing technique assessment tool for skiing instructors based on wearable technology. Thereto, the PMs were to be aligned with the qualitative descriptions of skiing technique variations as defined in skiing curricula [ÖSSV/Snowsport Austria, 2021].

Eight experienced and licensed skiing instructors performed parallel and carving turns as well as specified technique variations, namely forward- versus backward leaning, large versus little vertical motion, inward leaning versus hip bending, upper body rotation with versus against the turn. The volunteers' skiing movements were recorded using a Xsens™ body suit (Xsens Technologies B.V., Enschede, NL) comprising 17 inertial measurement units recording at 240Hz. Body movements were quantified through 22 reference points representing body joint positions in a reference frame attached to the volunteers' pelvis. The technique variation trials provided extremes for skiing technique variances to which the PMs then aligned, thus, the PMs provided scales on which specific technique features could be assessed.

Significant technique differences ($p<0.003$) were observed between parallel and carving turns in forward/backward leaning, in vertical body positioning and in upper body rotation.

While PMs have been used for technique analysis in several previous projects, this is the first study in which the orientation of the PMs were purposefully aligned with specific body movements to obtain a scientific technique quantification tool that matches practitioners' (skiing instructors) descriptions. Our tool can, for example, help aspirants for a state license as alpine skiing instructors, when they train the specific skiing techniques that have to be demonstrated during certification.

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ÖSSV/Snowsport Austria: https://www.snowsportaustria.at/ausbildung/berufsausbildung/

Machine Learning from Biomechanical Simulations for an "in the Wild" Movement Analysis

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In recent years, machine learning (ML) approaches to inertial sensor-based biomechanical analysis have attracted considerable attention [1]. This could be explained by the success of deep learning in other domains. Neural networks can directly learn mathematical relationships between sensor data and biomechanical variables without requiring expert knowledge of the physics. In addition, trained models can be used for real-time, low-latency applications (e.g., exoskeleton control or injury prevention). However, this requires a representative dataset for training. Collecting data can be costly, time-consuming, or even impracticable, especially, when movements on the field in unrestricted environments should be analyzed.

Data augmentation is a common approach to achieve better generalization of ML models, but only few attempts have been made for inertial sensor-based biomechanical analysis [2]. Recently, we proposed a novel approach on how a biomechanical model can be simulated to expand a small dataset for training deep convolutional neural networks (CNNs) [3]. Random motion trajectories were generated from the small dataset, which were then tracked by a biomechanical model solving trajectory optimization problems. Thus, dynamically consistent walking and running cycles could be simulated and inertial sensor data could be synthesized at any virtual sensor position. Afterwards, CNNs were trained based on measured and simulated inertial sensor data to estimate sagittal-plane biomechanics of walking and running.

Training with simulated data reduced the root-mean-square error of joint angles by up to 17-27%. The accuracy of joint moments and ground reaction forces improved only slightly when simulated data were added to the training data set, which could be explained by the simplified ground contact model. Using more advanced biomechanical models or unsupervised learning can potentially close this reality gap.

In this talk, we will present our latest research results [3] and discuss how data-driven and physics-based approaches can be combined for "in the wild" biomechanical applications.

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Objectifying Changes in Gait Mechanics due to Fatigue using Inertial Sensor Technology and Data Science to Assist Injury Prevention in Running

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Neuromuscular fatigue is a main risk factor for running related injuries, suggesting that the body in a fatigued state is less able to attenuate impact forces sufficiently while landing on the ground. Inertial sensor technology, combined with force sensing and modelling techniques, provide a base to understand changes in kinetic and kinematic parameters and the shock attenuation strategies the body uses to counteract the negative effects of fatigue during running. These methods can be used outside the lab to assess shock attenuation strategies in a real world setting.

The load on the knee can be estimated using modelling techniques that use optical or inertial data together with force plate data. The role of the knee in attenuating the shock due to the foot hitting the ground can be modelled using wavelet transform analysis. Both show a change in knee loading and shock attenuation from active to passive strategies. This shift in strategy was also witnessed in fatiguing experiments on the athletic track as well as during an actual marathon. Shock attenuation derived from accelerations at the tibia, sacrum and sternum showed that runners adopt a more passive strategy to attenuate the shock when fatigued, which might result in a higher risk of injuries (Reenalda et al. 2019). This passive mechanism means that instead of using muscle contractions to actively control the ankle, knee and hip as shock attenuators, the body relies more on elastic and bony structures to dissipate the impulse.

The load on the tibia can be modelled using kinetic and kinematic variables. This has already been demonstrated using optical mocap systems (Matijevich et al. 2019) but inertial sensor technology gives the opportunity to estimate tibial bone loading due to fatigue in the real world. To identify fatigue in the real world, machine learning approaches showed that statistical features of the data provide additional information over traditional biomechanics. It allows for sensor reduction to unobtrusively and accurately classify fatigue in runners (Marotta et al. 2021).

Novel approaches in inertial sensor technology together with new data analysis and modelling techniques provide valuable insights into the load on the body and the strategies used to cope with this load. Identified parameters and mechanisms can be used to feed back to runners to assist injury prevention.

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Chasing the Right Kind of Repeatability: The Link Between Practice, Movement & Performance Outcome Variability

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In the presentation I will examine the relationship between the variability of practice conditions, the variability of movements an athletes makes when executing a skill, and the variability of their performance outcomes. How do we best achieve consistently successful movement outcomes? Is the key "repeatable" movements? What is the purpose of adding variability to practice - adjustability vs adaptability.

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Part of “From the lab to the field: Applying principles of motor learning to coaching” symposium.

Behavioral Flexibility and Its Relevance to Skill Acquisition

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A hallmark of skilled motor performance is behavioral flexibility - i.e., experts can not only produce a movement pattern to reliably and efficiently achieve a given task outcome, but also possess the ability to change that movement pattern to fit a new context. For example, depending on the type of court surface, a skilled tennis player can alter their forehand to hit the ball to a specific location on the court. Although our knowledge of this phenomenon has existed at least since Nikolai Bernstein coined the phrase "repetition without repetition", empirical investigations of this phenomenon have received much less attention in the motor learning and skill acquisition literature. In this presentation, I will examine the role of behavioral flexibility and its relevance to motor skill acquisition.

First, I examine the evidence for such behavioral flexibility in both lab and field contexts. A particular focus will be on understanding different ways in which behavioral flexibility can emerge, how this flexibility changes with learning, and the relevance of this phenomenon for our understanding of movement variability, stability, and theories of skill acquisition.

Second, I highlight important challenges in understanding this phenomenon from a methodological viewpoint. Specifically, quantifying behavioral flexibility can be done at multiple levels of performance and addressing the issue of whether such flexibility is 'good' for learning requires the use of innovative experimental designs compared to those typically used in motor learning research.

Finally, I examine the role of these findings in informing practice strategies and its relevance for both developmental and elite sport contexts. Given that movement arises from a confluence of constraints on the organism, task and environment, a key point that emerges from this view is that understanding how these factors interact and influence behavioral flexibility may be critical to developing appropriate practice strategies.

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Decision Making in Navigation Tasks: Role of Temporal Pressure on Perceptual-Motor Performance & Learning

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In contact sports, like soccer, athletes must strategically navigate a cluttered and dynamic environment in order to perform a variety of tasks (e.g., receive the ball from a teammate, steal the ball from an opponent, head the ball to the goal). Two navigation challenges, evolving at different time scales, are at play. First, to successfully perform any of the sports tasks exemplified above, athletes need to get to particular locations in the field of play at specific times. Second, to comply with these relatively stable spatial–temporal demands of navigation, athletes must make action decisions, such as circumventing obstacles, in response to moment-to-moment changes in contextual conditions. Over the course of an event, athletes will make a very high number of these action decisions, which can be particularly challenging due to the competitive nature of sports, that is, athletes on one team actively engage with their opponents in ways that impede their progress toward the desired location. Therefore, the accuracy of decisions with respect to impediments to locomotion in the field of play is critical for safe and efficient performance. A common impediment to locomotion is a closing gap: athletes work together to obstruct their opponents' path and force them into an action decision (pass through the gap and continue on the desired path or take an alternative, less efficient course of action towards the desired location by swerving around the gap). A safe and efficient decision requires keen sensitive to the affordance of passability. In this talk, I will present the results of a study conducted to examine whether increased temporal pressure to arrive at a desired location modifies this sensitivity to affordance boundaries and how such sensitivity changes with experience. Thirty participants navigated toward a pre-specified waypoint in a virtual, sport inspired environment. To do so, they had to decide whether they could pass through closing gaps of virtual humans (and take the shortest route) or steer around them (and take a longer route). The decision boundary of participants who were time pressured to arrive at the pre-specified way point was initially biased toward end gaps of smaller sizes and was less reliably defined, resulting in a higher number of collisions. With experience, participants under pressure learned to exploit the affordance boundary effectively to comply with the temporal demands while those who were not under pressure made more conservative (i.e., safe but less efficient) decisions throughout the experiment. Results indicate that temporal pressure affects perceptual–motor processes supporting information pick up and shapes the information–action coupling that drives compliance with navigation demands. Theoretical and practical implications will be discussed, with particular focus on the important role of stressors in promoting perceptual-motor processes crucial for adaptability and hence, behavioral antifragility.

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Precision Phenomics: The Future of Injury Prevention in a Complex World

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The complex nature of musculoskeletal injury in sport makes both primary and secondary injury prevention difficult. And despite several decades of research designed to identify and target causal mechanisms, existing methods of assessment and intervention have failed to adequately stem the tide of these injuries. Sports medicine is therefore in need of a new approach that enables the precise profiling of the complex interactions of system components (and component processes) that underlie these injuries. In specialty (and sub-specialty) areas of oncology, immunology and pharmacology prevailing precision medicine approaches have shown great promise for profiling and targeting complex disease states. While this provides a starting point for rethinking injury prevention, a direct translation of this genomics-based treatment model to sports medicine is not generally practical, and its reductionist grounding is insufficient. Instead, a parallel approach and methodology is proposed that leverages behavioral phenomics in place of genomics. It incorporates concepts from both precision medicine and complex systems modeling, and leverages portable technologies to detect and intervene on deficits related to an athlete's readiness to adapt to variable environmental conditions. Specifically, it relies on the construction of a phenomic profile to index an athlete's injury risk. This profile is based on a multifaceted assessment of interacting factors that support an athlete's ability to modify behavior in response to dynamic sport environments. That is, it is an assessment of an athlete's phenotypic plasticity—a modifiable, global characteristic of an athlete's fitness, or ability to positively adapt to performance environment challenges. It is quantified via stress-response profiles, which are made up of indices of neural, epigenetic and perceptual-motor plasticity. These profiles are constructed with successive measurements of an athlete's behavioral responses obtained as the athlete performs within a task context under various levels of environmental stress. Importantly, the computation of phenotypic plasticity accounts for the dynamic nature of adaptive processes underlying functional performance, which emerge from the interaction of the athlete with the task environment (i.e., the athlete's behavioral dynamics). This metric is therefore highly sensitive to the behavioral transitions an athlete makes to achieve more efficient performance states and, specifically, behavioral change as a function of environmental change. Our team has developed a technology platform to profile the phenotypic plasticity of athletes using a combination of portable sensors, kinematic pose estimation and mixed-reality as a first step in support of a precision phenomics approach to sports medicine. Preliminary data collected from the platform will be presented, and future directions and applications of this platform will be discussed.

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Neurobiological Complexity, Allostasis and the Predictive Brain: Implications for Athletic Rehabilitation and 'Return to Play'

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Sports training theory, including rehabilitation and 'return to play' practices, were originally contextualised through the conceptual lens of the conventional biomedical model. The biomedical model perceives the brain as (predominantly) a passive 'stimulus–response' machine that first detects, then processes, sensory stimuli before subsequently generating proportionate responses. Similarly, the biomedical model perceives structural tissue damage as the primary cause of pain and dysfunction. Over the past 50 years, however, the inadequacies of the biomedical explanatory framework, in rationalising the basic operating procedures of brain and body, have become startlingly evident. The biomedical model, for example, fails to explain commonly observed medical phenomena, such as placebo and nocebo effects.

In contrast, in recent years, there has been a growing appreciation of the role of prediction and anticipation in driving multiple health outcomes. Recent formulations of the Predictive Processing framework provide a realistic, evidence-based conceptual model that coherently captures the integrated mechanisms collectively underpinning and enabling neurobiological robustness, while also explaining previously unexplained phenomena (such as placebo and nocebo effects).

Within this presentation, we explore how a deeper understanding of the role of predictive processing in modulating multiple neurobiological processes can help shape new rehabilitation and 'return to play' strategies, practices and processes.

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How to Unravel the Complexity of Sports Injuries – Asking Who Knows Best

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Contemporary views in sports medicine state that sports injuries are 'complex' phenomena. Recent publications proposed to analyse sports injury through the lenses of complexity, applying a systems approach to understand injuries aetiology 1–3. The complex context in which an injury happens needs to be explored. An injury happens in an athlete with many individual features as well as multiple extra-individual factors, in a specific culture, regulated by a specific association and taking place in a particular socio-economic class in a specific country4. A systems thinking approach can unravel the dynamic interrelations playing a role in sports injuries. Such approach can be applied in conjunction with qualitative research methods to gather perspectives of different stakeholders to better understand the context in which injury occurs5. By gathering information from different stakeholders it's possible to identify the main elements of a system, the various stakeholders and the interconnectedness between them6–8. Such an approach makes it possible to map opportunities and challenges for injury prevention in an specific setting and facilitate the future development of context-driven injury prevention strategies.

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Injury Prediction asa Nonlinear System

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The purpose of this presentation is to propose and explain the hypothesis that an athlete's resistance to injury is a nonlinear, dynamic system. As such, individual resistance to injury should not be viewed as a steady state, an inherent assumption in any pre-season testing model. We propose that, as with the tracking of a volatile weather pattern like a hurricane, frequent sampling of variables through athlete testing is a prerequisite to understanding the system dynamics and to detecting when there is a change in the resistance of the system to injury. Moreover, better detection of a change in the system could lead to a better understanding of which athlete is at a greater risk for injury-paramount in order to efficiently target preventative interventions.

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Metabolomics: Novel Biomarkers To Mitigate Injury Risk In Professional Football Players

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There is a very fine line between winning and losing in elite football. Positive adaptations to to training during preparation is a major determinant of football players likelihood to be successful at the international level. However, planning training programs to optimize physical performance in collective sports, such as football, is complex due to extensive intra- and inter-individual variability in the levels of adaptation under similar training loads. In this context, control and appropriate manipulation of workload is critical for optimizing performance while mitigating the risk of injury. Workload is typically classified as either external or internal. The external workload is the work done by the athlete (e.g. running distance, number of accelerations), and it can be measured using e.g. electronic performance tracking systems (EPTS) or simply as volume (e.g. minutes/hours trained/played). The internal workload is the relative biological stressors imposed on the player during training, and it manifests as the physiological response to that work (e.g. heart rate, body temperature). External and internal workloads thus represent different but closely linked aspects of training.

Metabolomics is an area of systems biology that studies the downstream products of gene regulation and expression, as well as their interaction with the environment. The analysis of the metabolome delivers a dynamic snapshot of the functional level of a biological system. Metabolic profiling of biofluids have shown short- and long-term exercise-induced metabolic responses involving amino acids and ATP metabolism, glycolysis, beta-oxidation of free fatty acids, and upregulation of the antioxidant system through complex enzymatic and non-enzymatic antioxidant adaptations. Here, we describe results obtained in the course of an observational longitudinal study to investigate the association between external workload EPTS measures and changes in the urinary metabolomic profile of professional football players throughout a complete season [1].

A total of 278 urine samples collected from 80 players were analyzed by UPLC–high resolution mass spectrometry. Multi- and univariate analysis, and functional metabolic pathway analysis of the retrieved urinary metabolomic profiles acquired, allowed the detection of changes associated to the external training load. The shift in the metabolic profiles indicated a change in the steroid hormone biosynthesis pathway, as well as in the metabolism of tryptophan and tyrosine. Moreover, the higher ratio of players showing a deviation from the multivariate model suffering a muscular injuries compared to those who did not, suggest that the approach could be implemented to identify situations of insufficient adaptation and elevated risk of muscle injury.

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Affordances and coordinated end-directed actions in the rondo drill in soccer

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The rondo drill, in which a team of exterior players arranged in a circle play keep-away from a smaller team of interior players, is a popular football (soccer) drill because it contains most of the fundamental elements of the game, in a much simpler form. For precisely these reasons, it also makes a suitable first model of the study of soccer. During play a complex dynamic system is formed by the activities of the two teams, each of which, in its agency and goal directed activity, forms (part of) the environment of the other team. To understand the rondo, therefore, is to understand the affordances for activity each team provides for the other, and the goal directed activity of the players on each team. As part of an ethnomethodological investigation of the actions interior players engage in, the goals of these actions, and the features of the players' perceptual flow field the players utilize to discriminate between actions, we report a Thematic Analysis five members of the FC Barcelona coaches academy analysis of interior play during the rondo. This analysis is possible because, though they utilize the actions and affordances differently and work at different speeds, players, coaches and researchers all aim to perceive the affordances present in a given situation, and the skillful actions players pursue based on those affordances. We then offer areas for future research mathematically modeling the interior player activity, both in its coordination and its end-directedness, including a fit between the mathematical theory and the empirical results. Here we will show how both, this empirical approach to sports, and the suggested mathematical models, have applications to team sports more generally.

Mathematical Analysis and Modeling of Dribble Dynamics

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Football is often deemed unpredictable because players make split-second decisions as they react to ever changing game conditions. Little is known about the underlying physical processes that happen on the pitch. In this paper, we investigate the dynamics of one of the game's most fundamental aspects: dribbling. Here, we present a novel and simple mathematical model that captures the essential dynamics of dribbles in a football match. The attacker and defender's movements are modeled by a pair of ordinary differential equations (ODE) with player specific parameters, which can be attributed to player's athletic abilities and football intelligence. Using game data from professional clubs, these parameters can be inversely computed from in-game dribbling situations using constraint optimization algorithms. They capture previously unquantifiable traits, reproduce the dribbling trajectories, and predict player attacking and defending behaviors. We show that the proposed attacker-defender model accurately reproduces the dynamics of real-game 1v1 dribbles, thus leading to a better understanding of the physics behind dribbling and paving the path towards quantifying more complex dribbling interactions. Potential applications of this model could be player evaluation and specific skill development. For instance, by comparing parameters of multiple players in specific game situations, and simulating the according dribbling behavior, coaches would be able to make more-informed decisions.

Modeling affordances for the analysis of the game

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Traditionally, sports analytics in football have commonly focused on probability, presented in terms of expected values. These approaches create a common metric for understanding every football situation in terms of a single variable, regardless of whether the starting point is event data, tracking data, or a combination of the two. The utility of any particular action or progression is reduced to a common denominator. This unification has advantages but also disadvantages. On the one hand, it allows for tactical decisions to be quantified and compared, to evaluate gameplay in terms of an outcome other than the final score of the match. On the other hand, it does not provide a clear point of contact with the usual way that coaching staffs work. Coaches do not need to know simply if a situation is good or bad, or if they are likely or not to score. Instead, coaches need feedback in their own language. In other words, they need to be able to understand the functional semantics of a situation based on a more verbal or commonsense description of what is happening: there is too much space between the lines, for example. This is what we set out to achieve at Kognia Sports Intelligence, using analytical toolkits from complex systems and related fields. In this talk, we will present how Kognia uses affordances to understand tactical situations of the game in a similar way as expert coaches do.

Meaningful Synergies of Movement

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Degeneracy, multifunctionality, invariance properties, compression of configurational degrees of freedom, etc., are now well-established features of synergies. In this talk I will address the (less appreciated) creative and generative aspect of synergies using film and motion analysis of ballet dancing and examples from complex sports settings. All further support the concept of synergy as the meaningful functional unit of the science of coordination, Coordination Dynamics.

Complex Brain in Dance

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To date, most neurophysiological dance research has been conducted exclusively with female participants in observational studies (Cross et al., 2006; Fink et al., 2009; Pilgramm et al., 2010; Jola et al., 2012; Bachrach et al., 2016; Poikonen et al., 2018a; Poikonen et al., 2018b). In this regard, the sex-specific acute neurophysiological effect of physically executed dance represents a widely unexplored field of research. The current study examines the acute impact on brain activity and functional connectivity of a modern jazz dance choreography using electroencephalography (EEG).

In a within-subject design, eleven female and eleven male participants were examined under four test conditions: physically dancing the choreography with and without music and imagining the choreography with and without music. Prior to the EEG measurements, participants learned the choreography over three weeks. Subsequently, participants conducted all four test conditions in a randomised order on a single day, with EEG measurements taken before and after each condition.

Differences between male and female participants were established in a brain activity and a functional connectivity analysis in the imagined dance without music. No differences between sexes were revealed in the physically executed dance with and without music as well as in the imagined dance with music.

In consequence, sex-specific effects of dance provide an enormous resource of gaining a more differentiated and more holistic understanding of movement. In addition, sex-specific effects could be used to achieve a more targeted and individual application of dance interventions, for example, in the context of sports and therapy.

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Synchrony and social signaling in dance performance and dance appreciation

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Synchronizing movements between individual performers is a central aspect of team sports, dance and music performance. In two experiments, we investigated performing and perceiving synchronous movements in live dance. We conducted two large-scale experiments (N > 100) in which participants performed a set of movement tasks that were either performed as a group or individually. During performing and watching these tasks, we assessed movement synchrony based on performer acceleration and spectators' psychophysiological responses using wrist sensors. We also recorded continuous ratings of aesthetic appreciation and perceived group characteristics. We show that movement synchrony is associated with group affiliation among performers and predicts spectators' heart rate and enjoyment. Our findings point to an evolutionary function of dance in communicating social signals between groups.

Multisensory Perspectives on Dance

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Dance offers a wealth of aspects that can be the subject of research as well as methodical approaches to gain knowledge. If one regards dance as a communicative process, its mode is primarily visual, and its medium is the dancer's body, which is above all to be seen, and watched by an audience — this is where dance differs from music with which it shares common evolutionary roots. Dance, however, offers more than a visual experience, it relies on contributions from the different sensory modalities, their special qualities and their integration into a holistic, mostly as a consistent unit experienced body. The aesthetic experience evoked by the visual experience of dance is thus a multisensory one that is based on kinaesthetic synaesthesia. Aesthetic pleasure can derive from the fusion of multimodal and multi-layered perceptions leading to increased embodiment and inner simulation of movement, resulting in kinesthetic empathy and, potentially, feelings of physical enthusiasm, or flow. The memory processes supporting dance on many levels are based on the integration of multimodal (motor, visual, acoustic, tactile, proprioceptive, kinesthetic, vestibular) information with spatial, temporal and semantic aspects. Learning processes in dance require the integration of different forms of memory and challenge their conceptual boundaries. Dance-specific strategies that combine movement simulation and movement execution can support memory-based processes in learning, adapting, creating and improvising movement. For dancers, the body is not only the basis of self-perception, but also an instrument and tool in their artistic work, in which multimodal representations of body, movement, space and time play a central role. The perspective taken here is that, despite the primarily visual character of dance as an art form and mode of communication, a non-exclusively visual approach has the potential to enable any audience, sighted or not, to experience dance in an enriching way. It is motivated by the question how dance can be made accessible for audience members who are blind or visually impaired, aiming to support cultural participation. Equally important is the notion that dance itself can be regarded as laboratory in which researchers strive to explore and expand the boundaries of human perception and cultural concepts. Finally, this approach can inspire research questions and motivate hypotheses for future studies in cognitive, movement and sport science that acknowledge both scientific and artistic perspectives.

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Influences of Tempo, Laterality, and Expertise on Dance-like Movement Consistency

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In dance, music, or sports, reproducibility and consistency of movement and movement sequences is very important, in particular in repeated motion. Despite a certain inherent variability, consistency as well as lateral symmetry of movement are crucial for motor control, enhancing individual capability, reliability, and stability of performance outcomes and furthermore for preventing injuries (Preatoni et al., 2013).

In order to address velocity consistency – that is being able to conduct a movement with a constant speed – in an artistic setting, a repeating dance-like movement routine was developed. Effects of tempo, body laterality, and expertise in music and dance were assessed in relation to this measure.

Thirty-six participants (23 female, average age 27.4 years) were instructed to perform a repetitive circular, ipsilateral motion of arms and legs at three different tempi for 30 seconds each, while being recorded with optical motion capture. Years of dance and music training as well as the short Edinburgh Handedness Inventory were assessed. Two consistency measures of velocity profiles were developed: an overall measure of consistency based on the standard deviations of each body side, and a difference measure between right- and left-side consistencies.

Mixed ANOVAs were conducted to assess effects of tempo, laterality, and music respectively dance expertise on velocity consistency. For overall consistency, significant differences between slow and fast as well as slow and mid tempo performances were found: participants showed higher consistency in fast and mid tempo performances than in slow ones. Moreover, we found significant differences between musically low-level and both mid-level and high-level trained participants on the subdominant body side: mid- and high-level trained participants performed with higher consistency than low-level trained participants. Dance expertise failed to show a significant effect regarding overall consistency. The difference measure indicated that musically less trained participants were significantly more consistent in their dominant-side velocity, compared to musically high-level trained participants, who were more consistent on their subdominant side. Participants with no dance background were more consistent on their subdominant side, while mid-level trained participants were more consistent on their dominant side. Interestingly, participants with high-level dance training were similarly consistent on both sides.

Overall, these results show differences regarding velocity consistency and body control, suggesting a stronger influence of music expertise on the ability to maintain a consistent velocity in a repetitive circular task than dance background. Outcomes could have potential implications on music instrument, dance, and maybe even sports practice and training.

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Dr. Birgitta Burger is a postdoctoral researcher funded by the ERC project SloMo at the University of Hamburg. She is investigating the role of the body in production, perception, and understanding of music with a focus on music-induced movement, synchronization, and entrainment. Furthermore, she is co-developing Mocap Toolbox, a Matlab Toolbox for visualizing and analyzing motion capture data.

The Dance Creativity Paradox

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Dancers need creativity to improvise, compose or be coupled with their dance partners. The use of constraints to foster creativity has been studied in different domains, especially in art (Stokes, 2008). In dance, it has been investigated with the practice: the choreographers usually look for different limitations to create and contemporary dance teachers propose task constraints to increase the students' creativity and exploration. Nevertheless, literature related with the use of constraints to foster dance creativity is scarce.

Based on recent research, this presentation aims to explain how constraints can release degrees of freedom while dancing. It also aims to clarify the processuality of creative behavior taking into account the interrelatedness and nestedness of constraints acting on the system (Balagué, Pol, Torrents, Ric, & Hristovski, 2019; Torrents, Balagué, Ric, & Hristovski, 2020). This is especially important in movement-based practices, as the specificity of motor creativity is conditioned by the time scale where actions emerge compared with other domains.

Using a complex dynamical systems approach, it will be discussed how constraints form boundaries around the exploration of certain action possibilities, while allowing the emergence of other exploration possibilities. These actions emerge from the nonlinear interaction between the intrinsic dynamics of the creator and environmental constraints. Moreover, self-interaction and co-adaptive loops, as well as the interaction of all constraints acting on the system at different time scales, allow the emergence of creative behaviour. Some contemporary dance examples related with the use of task constraints (dancing with or without partner, close or far from the other person, and with or without mirror) from our lab will be presented (Aragonés, Coterón, Ric, & Torrents, 2020; Torrents, Ric, & Hristovski, 2015).

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Network Physiology of Exercise: bridging the gap

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Exercise Physiology studies the functioning of the organism during physical exercise and scientifically grounds questions ranging from high-performance to exercise as a medicine. Although physiology is the only branch of biology dealing with synthesis and integration, Exercise Physiology and its main research directions, strongly influenced by reductionism, have progressively evolved towards biochemistry, molecular biology, genetics and OMICS technologies. Despite the fact that these technologies represent new ways to unravel knowledge and deal with multidisciplinary approaches, the dominant research of Exercise Physiology is methodologically still focused on non-dynamical statistical inference techniques.

Inspired by the new field of Network Physiology and Complex Systems Science, Network Physiology of Exercise emerges to fill the gap of current trends of Integrative Exercise Physiology. Transforming the theoretical assumptions of Exercise Physiology, currently overlooking the properties of complex adaptive systems, it transforms its research program and its practical applications with relevant consequences on performance and health. In collaboration with diverse disciplines like bioinformatics, data science, applied mathematics, statistical physics, complex systems science and nonlinear dynamics, Network Physiology of Exercise focuses the research efforts on improving the knowledge and understanding of the nested dynamics of the vertical and horizontal network interactions characterizing the emergence of different physiological states and functions.

In this communication we will discuss the main biases and pitfalls of current Exercise Physiology and illustrate the potential impact of Network Physiology of Exercise providing a renewed understanding of exercise-related phenomena and contributing to enrich Basic Physiology and diverse fields connected to Exercise like Sports Medicine, Sports Rehabilitation and Sport Science among others.

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Hypoxic and Hypercapnic Responses and Cardiorespiratory Coordination in Endurance Athletes and Mountaineers

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Coordination between subsystems is a distinctive feature of the physiological state. Cardiorespiratory coordination (CRC) plays an important role in the regulation of gas exchange, which occurs with the participation of central and peripheral chemoreceptors. The features of the CRC largely determine the individual reserves of endurance athletes. CRC in hypoxic and hypercapnic tests can serve as an additional marker of specific mechanisms of adaptation to various hypoxic conditions, including high-altitude hypoxia in mountaineers, and sports in which the result depends on the state of the oxygen transport system and its regulation.

Seventy-seven young male athletes of high qualification level (skiers, runners, swimmers and mountaineers) and twenty healthy male non-athletes (control group) were examined. We used the following tests: normobaric hypoxia, hypercapnia and a progressive maximal cycling test. Respiration and gas exchange variables and heart rate were continuously recorded on the Oxycon Pro ergospirometric system (Erich Jaeger, Germany). The electroencephalogram (EEG) and heart rate variability were evaluated in the stationary state and normobaric hypoxia. Principal component (PC) analysis was performed on the time series of cardiorespiratory variables to assess cardiorespiratory coordination for each participant.

Results. Specific phenotypic features of gas exchange regulation and chemoreflex responses in athletes, in relation to the type of sport, which are manifested in the parameters of hypoxic and hypercapnic ventilatory and cardiac reactivity, patterns of breathing, gas exchange, autonomic nervous system activity and EEG, are established. These changes in the regulatory mechanisms have a specific effect on the functional reserves of the athletes' respiratory and cardiac systems during intensive muscle work. It is shown that with the growth of sports qualification, the neurophysiological mechanisms of cardiorespiratory functional coordination are improved, which are manifested in the optimization (accuracy) of the responses to changes in the CO_2 and O_2 blood levels. It is found that acute hypercapnia has a coordinating effect on the cardio-respiratory system. On the contrary, acute hypoxia reduces CRC. In highly qualified athletes, cardio-respiratory stability under hypoxic exposure is higher than in medium-trained athletes.

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Towards A Three-Dimensional Dynamical Systems Framework Of Perceived Fatigability

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Traditionally, exercise physiologists rely on critical endpoints in cardiovascular, respiratory, metabolic, or neuromuscular systems and proportional exercise-induced responses to explain disengagement from linear laboratory tasks. However, under complex conditions these critical delimiter models are plagued by logical limitations necessitating the acceptance of paradoxes. Likewise, perceived exertion-centric models of exercise regulation rely on scalar properties in a single one-dimensional variable and invariant setpoints in homeostatic or motivational parameters to predict exercise behaviour. Such models treat the human organism as a computational device within a traditional control framework, where task-disengagement is considered a voluntary decision. But they cannot account for sudden non-proportional changes in susceptibility to fatigue or delineations in the perceived exertion-performance relationship (the very essence of race-decisive moments in endurance competitions) without reverting to ad-hoc explanations. Instead, the regulation of exercise performance is better understood as a complex, goal-directed, and context-dependent behaviour adapting to the interaction of emerging organismic and environmental constraints.

Long-distance endurance events are characterised by great levels of fatigue as well as volition to contend against fatigue-constraints over prolonged periods. Such events therefore provide an excellent platform to investigate effects of accumulating fatigue on (in)stability in sensory, affective, and cognitive states as well as performance. When a set of components becomes fatigued, synergetic compensations are required to maintain overall performance. The ability to form new bio-psycho-social synergies allows to compensate for functional losses in fatigued components and maintain stability in coordinative variables. Utilizing a three-dimensional framework of perceived fatigability provided novel insights into the cascading psychophysiological mechanisms that underpin the escalating destabilisation of volition to continue goal-striving during self-paced endurance exercise [1]. Specifically, the affect-driven shift from an implemental to a deliberative mindset lead to the emergence of a decisional conflict between further goal-pursuit and goal-disengagement, and eventually the spontaneous dissolution of the initially aspired goal.

Fatigue-induced goal-disengagement and task termination are therefore neither considered a catastrophic failure in one or other system nor a voluntary decision. From a nonlinear dynamical systems perspective, goal-disengagement spontaneously emerges through self-organisation from bio-psycho-social interactions bounded by fatigue constraints over time. This is indicative of a protective circular mechanism enforcing abrupt destabilization of volition to continue goal-striving when approaching exhaustion.

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Complex Networks of Cross-Communication between Cortical Waves and Muscle Activity Rhythms

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Skeletal muscle activation is continuously modulated across physiologic states to provide coordination, flexibility and reaction to body tasks and external inputs. Despite the central role the muscular system plays in facilitating vital body functions, the network of cortico-muscular interactions required to control hundreds of muscles and synchronize their activity in relation to distinct physiologic states has not been investigated. Recent approaches have employed general associations between individual cortical rhythms and muscle activation during movement tasks. However, the specific forms of coupling, the functional network of brain-muscle coordination, and how network structure and dynamics are modulated by autonomic regulation across physiologic states remains not understood. To identify and quantify the brain-muscle interaction network and uncover basic features of neuro-autonomic control of muscle function, we investigate the coupling between synchronous bursts in cortical rhythms and peripheral muscle activation during sleep and wake. Utilizing the concept of time delay stability and a novel network physiology approach, we find that the cortico-muscular network exhibits complex dynamic patterns of communication involving multiple cortical rhythms across brain locations and different electromyographic frequency bands. Furthermore, our results show that during each physiologic state the brain-muscle network is characterized by a specific profile of network links strength, where particular cortical rhythms play role of main mediators of interaction and control. Moreover, we discover a hierarchical reorganization in network structure across physiologic states, with high connectivity and network link strength during wake, intermediate during REM and light sleep, and low during deep sleep, a sleep-stage stratification that demonstrates a unique association between physiologic states and brain-muscle network structure. The reported empirical observations are consistent across individual subjects, indicating universal behavior in network structure and dynamics, and high sensitivity of brain-muscle control to changes in autonomic regulation, even at low levels of physical activity and muscle tone during sleep. Our findings demonstrate previously unrecognized basic principles of cortico-muscular network communication and control, and provide new perspectives on the regulatory mechanisms of brain dynamics and muscle activation, with potential clinical implications

for neurodegenerative, movement and sleep disorders, and for developing efficient treatment strategies.

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ORAL PRESENTATIONS

The Effect of Differential Repeated Sprint Training on Physical Performance in Female Basketball Players: A Pilot Study

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Team-sports require the players ability to perform repeated bouts of sprinting, jumping, and cutting activities, interspersed with periods of low-to-moderate intensity actions (1). Consequently, it is astute that practitioners develop methods of enhancing the ability to repeated high-intensity actions and adequately match the specific team-sport requirements. Furthermore, these activities are performed during the game in unpredictable situations and in different contexts, requiring methods that promote both the ability to adapt to interchangeable environment. One possibility is use differential learning principles, including continuous confrontation with new movement challenges, resulting in flexible and adaptable movement patterns (2,3), and improved physical skills in team-sport players (4–6). This study aimed to determine the effects of differential learning in sprint running with and without changes of direction (COD) on physical performance parameters in female basketball players. Sixteen female basketball players (age: 19.0±2.4 years) completed 4 weeks of repeated sprint training (RST) with (COD, n=4) or without (NCOD, n=5) changes of direction. A battery of sprints (0-10 and 0-25m), vertical jumps (counter movement jump [CMJ], drop jump, and single-leg CMJs), and COD tests (505 test) were conducted before and after intervention. Furthermore, lower limb asymmetry index was calculated for jumping, sprint and COD tests. Also, the COD deficit (CODD) was calculated. The NCOD group completed two sets of ten sprints of 20 m, whereas COD performed 20m sprints with a 180 degree turn at 10m returning to the starting line. Both groups had 30s of passive recovery between two sprints and 3 minutes between sets. Before each sprint, participants were instructed to provide different fluctuations in terms varying the sprint (e.g., blinking eyes, two arms up, crossed arms, etc.). No fluctuation was repeated more than once in each training session. A two-way repeated measures ANOVA revealed a main effect of time ($p<0.05$) for

0-10m sprint, CMJ, single leg-CMJ asymmetries, and an interaction for left-leg CMJ performance, favouring COD training group ($p<0.05$). Differential learning in sprint running with and without COD results in comparable improvements in a broad range of sprint, jump, and COD tests. The findings of the present study displayed positive effects of adding fluctuation in repeated sprint training which indicates that pursuing this research field is worthwhile. This training type is recommended for further experiments in female basketball, where coaches and fitness trainers might go beyond their learned tools and switch from convergent and teacher-oriented training to more divergent thinking approaches with athlete-oriented training.

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Individualized Speed Threshold To Quantify External Load

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New researches suggest that quantifying the distance traveled based on individualized speed thresholds could offer us greater accuracy when it comes to quantifying the workload developed by the players. The individualized speed thresholds have been obtained by dividing the individual maximum speed (MS) into different ranges (Núñez et al., 2017, Murray et al., 2018, O'Connor et al., 2019).

Núñez et al. (2017) compared the running demands (m/min) of soccer players between playing positions with absolute: relative distance covered at very low intensity (VLIR, 0-7 km/h), relative distance covered at low intensity (LIR, 7-13 km/h), relative distance covered at moderate intensity (MIR, 13-18 km/h), relative distance covered at high intensity (HIR, 18-21 km/h) and relative distance covered at very high intensity (VHIR, >21 km/h); and relative speed thresholds: divisions of 10% between the maximum speed reached in a 40 m sprint test. Murray et al. (2018) examined the differences in absolute and relative load using four absolute speed thresholds: distance covered at low speed (LSD, <6 km/h), distance covered at moderate speed (MSD, 6-18 km/h), distance covered at high speed (HSD, 18-24 km/h) and distance covered at very high speed (VHSD, >24 km/h); and four relative speed threshold based on his maximal speed reached in season: low speed (0-19,99% MS), moderate speed (20,54,99% MS), high speed (55-74,99% MS) and very high speed (> 75% MS). Furthermore, O'Connor et al. (2019), compared the use of absolute sprint thresholds: distance covered >24,9 km/h; and relative sprint thresholds: distance covered >75%, >80%, >85%, >09% and >95% of individual MS. and determine their relationship with the incidence of non-contact soft tissue injuries and stress bone breaks/fractures of the lower limbs.

Both studies suggest that using speed thresholds based on maximum speed provides greater accuracy when it comes to qualifying the physical load of the players and better training prescription (Núñez et al., 2017, Murray et al., 2018, O'Connor et al., 2019).

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The Ecological Approach to Perception & Action in Iso-Inertial Resistance Training with Soccer Players

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The introduction of constraints-led approach (ball condition) in training settings has been shown to influence a greater acceleration in the execution of coordinative actions with resistance, and an increase of entropy (1). This can be explained based on principles from ecological psychology that entail a necessary commensurability between the degrees of freedom of the organism and its environment (athlete – ball conditions) (2). It has recently been noticed that eccentric-overload coordination training with the introduction of sport-specific constraints has a positive effect on the performance of young handball players (3). The present study aims to analyze the muscle-power effects (positive fluctuations and maximal power) in two experimental conditions: manipulation of sport-specific constraints (CM) vs no manipulation of constraints (NC) under the tenets of the ecological approach to perception and action (2,4). Thirteen soccer players (age: 22.3 ± 1.1 years) participated in this randomized cross-over trial. A crossover step exercise with sport-specific constraints (attacker decision based on defender action) was carried out, and the same test was executed without constraints to compare both conditions. Muscle-power (eccentric and concentric variables) was assessed. Significant main effects were found in muscle actions ($p = 0.007$, $\eta^2p = 0.47$) both in the CM and NC conditions ($p = 0.018$, $\eta^2p = 0.38$). A significant interaction was shown between muscle action, set and leg factors ($p = 0.004$, $\eta^2p = 0.38$). Post-hoc tests revealed lower power outputs in CON than in EXC muscle actions (MD = -69.25 W 95% CI [-115.99, -22.50]). Furthermore, greater power outputs were obtained in NC (MD = 88.43 W 95% CI [18.01, 158.85]). Significant main effects were shown in muscle actions ($p < 0.001$, $\eta^2p = 0.72$) and in the presence or absence of stimulus ($p = 0.032$, $\eta^2p = 0.33$). Post-hoc tests revealed greater CV in CON than in EXC

muscle actions (MD = 4.8% 95% CI [2.9, 6.8]). Furthermore, greater CV was shown in CM than in NC condition (MD = -4.5% 95% CI [-8.6, -0.5]). Present findings suggested major power fluctuations when performing the exercise with a decision-making constraint. These stochastic-perturbations provoke constant body readjustments, leading to a continuous variability of the resulting neuromuscular strategies (5), which has been identified as a determining factor in the new perspectives of strength training (6). Otherwise, larger concentric power (acceleration phase) was found under no-decision making conditions, probably because perception aspects were not disturbing the production of tension. Finally, the manipulation of performance-specific constraints disclosed a potential positive effect on the development of strength which, in turn, may hold important practical applications for strength and conditioning coaches when facing the selection of the most effective training method to optimize performance.

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Effect Of Specific Program Of Strength And Plyometric Exercises On Acceleration Skating Speed And Jumping In 14-15 Years Old Ice Hockey Players

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The most important factor influencing the course and result of an ice hockey game is speed. The aim of our study was to determine the effect of strength exercises in combination with plyometric exercises on the development of explosive strength of the lower limbs and the subsequent transformation into the acceleration speed of skating and jumping in 14-15 year old ice hockey players.

In our research participated 33 ice hockey players (Male; age: 14.7 ± 0.7; hight: 165.5 cm ± 7.3; weight: 53.4 kg ± 6.9) divided into experimental (n = 18) and control groups (n = 15). The experimental group consisted of 9th grade players of the HC 05 BB team and the control group consisted of 9th grade players of MHC Martin. Both teams play the highest Slovak league.

Input, output and post-experimental measurements were performed at 8-week intervals. The tests on-ice consisted of an acceleration speed of 5, 10, 20 m distance and an acceleration speed of 40 m with changes of direction and three tests off-ice, such as horizontal jump, squat jump and countermovement jump. For the processing of statistical data, we inferred the differences of the mean values ??using the effect size theory (ES; Cohen, 1988; Hopkins, 2016) as small (d = 0.20), medium (d = 0.50), large (d = 0.80) or uses for values d <0.2 interpretation „trivial“.

Players in the experimental group and in the control group completed 5 training units on-ice, 2 training units off-ice in the range of 60 minutes and 1 match. In the experimental group, an experimental factor of 2 training units of strength-plyometric exercises was added in the range from 20 to 30 minutes before the training unit on-ice in the form of a circular exercise, where they performed 360 and 366 different jumps.

The results show that in the test at 5, 10 and 20 m in the experimental group there was an improvement between input and output (effect size medium d = 0.50), in the test at 40 m with changes of direction there was also an improvement between input and output (effect size small d = 0.20). In tests off-ice CMJ, SJ and horizontal jump, there was also an improvement between input and output testing in the experimental group. In off-ice tests, players in the control group also improved between input and output testing, but the effect size was smaller. On-ice tests showed that the players in the control group slight improvements between the input and output tests, but there was a deterioration in the 10 m test. Post-experimental tests also point to the long-term effect of strength exercises in combination with plyometric exercises, which is proved by the results of virtually all tests except the test of the acceleration speed of skating at 10 m.

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Leveraging Load-response Profiles to Enhance Athletic Performance

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Research on complex biological systems has shown that exposure to certain stress-loadings may be beneficial for the system to trigger adaptive responses. For example, immune systems may facilitate their functioning when being exposed to a certain dosage of a potentially harmful infectious agents (i.e., vaccinations). Thereby, the loading (i.e., dosage) and the facilitative response form a biphasic relationship: The immune response increases with increasing loading until the pattern is reversed and increasing loading starts to have a toxic effect on the system. In this talk, I aim to demonstrate how this idea can be applied in the domain of human performance. I will present a study in which we assessed the relationship between loading and behavioral responses in climbers. Specifically, we asked professional route setters to design 11 bouldering routes with increasing difficulty, which represent the increasing loading. Then, we observed the degree to which athletes completed the routes and how many attempts they needed. In line with the findings of typical load-response profiles in other systems, we hypothesized that athletes who reach the same maximum performance may respond very differently to loadings. In line with this hypothesis, we found that the athletes who reach a similar maximum performance showed a large variety of profiles given by the area under the load-response curve. However, contrary to our expectations, the load-response profiles did not show a clear biphasic relationship. Instead, the easiest routes were completed by the athletes in a single attempt, yielding the maximum response score. Therefore, we did not see an increase in responses with increasing loading, but only the second phase of the biphasic relationship. This finding may be explained by the fact that a baseline where loading is absent may not be measurable with behavioral response variables. Nevertheless, the resulting profiles allowed us to derive routes that were optimally challenging the athletes while still being able to perform on the task adequately. Therefore, this approach may provide a promising avenue for exposing athletes to optimal loading levels to improve performance.

Moving Minds Distracted - The Impact Of Smartphone Use On Collision Avoidance In Human Locomotion

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In recent years, the number of accidents involving pedestrians using mobile phones has been rising. Studies on the impact of dual-task distraction on collision avoidance in virtual environments have yielded inconclusive results (Chopra, et al., 2018; Deblock-Bellamy, et al., 2021). To better understand cognitive-motor interference effects of using the mobile phone while walking, we performed a study in which young adults had to perform a locomotor task under different cognitive and motor multi-tasking demands.

Ten participants performed a collision avoidance task in which they had to walk under four conditions: walking without mobile phone use and without an interferer crossing path (BL), walking without mobile phone use but with an interferer crossing the path (IO), walking while using the mobile phone without an interferer crossing the path (DT), and walking while using the mobile phone with an interferer crossing the path (MT). Parameters quantifying locomotor and collision avoidance behavior were assessed using optical motion tracking. In addition, performance in the mobile phone task was assessed.

Participants' locomotor behavior was significantly affected by multi-tasking demands, as indicated by a main effect of condition on path length ($F(1.08,9.75) = 14.48$; $p = .003$), and walking speed ($F(1.61,14.52) = 61.99$; $p < .001$). Post-hoc pairwise comparisons indicated additive effects of cognitive-motor demands on both, path length (BL = DT < IO < MT) and walking speed (BL > IO > DT > MT). Further, the number of errors in the mobile phone task was increased when performed while walking as compared to standing still, as indicated by a main effect of condition ($F(2,18) = 9.235$, $p = .002$). Importantly, collision avoidance behavior was influenced by cognitive-motor multi-tasking demands, with minimum distance to the interferer being significantly higher in the MT-condition, as compared to the IO-condition ($df = 9$, $t = -2.59$; $p = .029$).

In sum, our results suggest multi-tasking interference effects of mobile phone use during human locomotion. Specifically, while dual-task distraction due to mobile phone use seems to impact both, walking speed and performance in the mobile phone task, additional cognitive-motor demands due to collision avoidance demands seem to affect path length and walking speed, but not mobile phone task performance. In addition, collision avoidance strategies seem to be proactively adjusted towards a more cautious strategy, resulting in an increased minimum distance between pedestrian and interferer.

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The Influence of Changing Constraints on Resilience in Human Movement

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Resilience in human movement performance (e.g., sports) can be conceptualized as a dynamic process. However, there is a lack of analytical tools in behavioral sciences to capture how this process unfolds over time. To fill this void, research on other complex biological systems, such as eco-systems, can provide important clues. Specifically, in ecology resilience is captured by analyzing (a) the deviation from the system's equilibrium and (b) the time it takes to return to this state following a perturbation caused by a stressor (i.e., an event the system needs to adapt to). Using this analysis, it has been found that eco-systems may lose their resilience when exposed to repeated perturbations. The aim of the current study was to translate this approach to human movement performance: we mapped changes of resilience in human movement by (a) analyzing the deviation from an equilibrium movement state and (b) the time it takes to return to this state following repeated perturbations to the movement pattern. We hypothesized that similar to eco-systems, resilience may be lost in human movement performance when the system is exposed to repeated perturbations. Therefore, we designed computerized Fitts task during which we measured (changes in) movements of a cursor on a computer screen at a frequency of 20Hz. Repeated perturbations were introduced by changing task (i.e., cursor movement sensitivity) or organismic (i.e., visual occlusion) constraints at fixed intervals of 30 seconds. Using linear mixed models, we found that contrary to our hypothesis, resilience scores actually improved following organismic-related perturbations ($n = 20$, $p = .029$), task-related perturbations ($n = 19$, $p = .13$), and when both types of perturbations were manipulated in an alternated manner ($n = 20$, $p = .009$). These findings show that resilience in human movement performance may not necessarily be lost, but can actually improve by exposing the system to repeated constraints under certain circumstances. These results imply that training movement patterns with repeated perturbations may foster improvements in performance.

Resilient Athletes: A Multidisciplinary, Personalized Approach

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Introduction: Competing at a high level in sports is inevitably connected to stressors such as high training loads, defeats, or injuries.1 In order to deal with these stressors, athletes need to be resilient, that is, they need to adapt and return to their previous performance level. Research has shown that resilience is a complex process, which emerges out of dynamic interactions between psychological and physiological components.2 To improve resilience, it is therefore important to monitor these dynamic interactions. Any attempt to better understand and subsequently manipulate these dynamic interactions requires an integration of knowledge on psychology, human movement science, data science, and a close collaboration with the sports field.

Project aims: With an interdisciplinary consortium, we are performing a 4-year project to understand and improve the resilience of athletes. First, we need to understand the source and response of psychological and physiological stressors that athletes encounter so that we can identify if athletes responses to stressors deviate from their normal states. When this deviation is abnormal, we consider this as a resilience lapse. Second, we will provide athletes and coaches with personalized feedback on their resilience state.

Methods: Data on mental and physical states are collected in three top-ten soccer clubs in the Netherlands using sensors and a purpose-built app. The data is automatically integrated in a secured data platform. In collaboration with data scientists we develop personalized models using pattern mining techniques such as Subgroup Discovery. These techniques will 'search' for meaningful patterns in the psychological and physiological states of the athletes.3 In the end, personalized models will be made, which players and staff can receive on their phone.

Expected results: The personalized models learn typical levels of the mental and physical functioning of each individual player. Vulnerabilities, which are detected by the algorithm, will be communicated to the coach and the player through our app. In that way they can undertake action before a mental breakdown or an injury occurs, so that players can maintain high performance.

Discussion: Improvement of performance, physical and mental health, and the reduction of injuries is of major importance in elite athletes. This project aims to advance our knowledge in understanding, measuring, and predicting resilience. Ultimately, with our multidisciplinary and personalized approach, we intend to transfer the knowledge on resilience in football to other team sports.

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Monitoring Effort Accumulation Through The Hysteresis Area Of Psychobiological Variables

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The hysteresis phenomenon, studied in exercising biological systems, has referred to the dependence of system's psychobiological state on the direction of change of the workload control parameter (Hristovski et al., 2010). This is called history dependence. This dependence creates a hysteresis area that reflects the recovery efficiency of the variable under study (Montull et al., 2020). Previous research has shown that athlete's expertise is associated with a lower hysteresis area of psychobiological variables. In this research we aimed testing if the hysteresis areas of the rate of perceived exertion (RPE), heart rate (HR) and muscle oxyhaemoglobin concentration (muscle O2Hb), respectively, were sensitive to effort accumulation over multiple bouts of exercise. For each bout, the control parameter of the psychobiological dynamics was the effort-recovery length. Ten physical education students participated voluntarily in the study. They performed five consecutive running bouts of 100 sec. at maximal aerobic velocity separated by different resting periods (until participants reported an RPE $\leq$ 11, Borg's 6-20 scale). The hysteresis areas of every variable were calculated, and their magnitude were compared using Friedman ANOVA and Wilcoxon test. In addition, Cohen's d was used to compare the effect size of the initial values between bouts. The hysteresis areas of the studied variables were different between the first bouts compared with the last ones: RPE and HR increased ($Z = -1.99$, $p = 0.04$; $Z = -2.19$, $p = 0.03$, respectively), while muscle O2Hb decreased ($Z = -2.80$, $p = 0.001$). In contrast with the values of RPE, HR and muscle O2Hb that were quite similar before each bout, the hysteresis areas showed an increased positive memory effect on RPE and HR and a negative one on the muscle O2Hb with bouts accumulation. Thus, the hysteresis area points as a promising variable for acute fatigue monitoring. Further research is warranted to explore how the hysteresis area of psychobiological variables relates with the multiple and embedded physiological networks that feature the complex behaviour of biological systems (Balagué et al., 2020).

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Teaching and Learning Coordination Dynamics Principles Through Movement Analogies in Highshool

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Highschool education, based on a fragmented structure of disciplines, limits reasoning and critical thinking of students, contributing little to the development of integrative knowledge considered essential in modern society (Hristovski et al., 2014). Coordination dynamics (CD) offers a set of general concepts which may contribute to develop knowledge integration and Kolb's (1984) experiential learning approach an adequate procedure for the comprehension of such integrative concepts (Hristovski et al., 2020). The aim of this research was evaluating the efficacy of teaching CD concepts through movement analogies on the integration and transfer of knowledge in first grade highschool students. Sixty six students and two teachers participated in the research. Students followed four learning phases: a) Movement experience (slackline and acrosport activities), b) Reflective observation of the experience (video-recorded), c) Abstract conceptualization of the experience using four concepts (stability, contraints, instability and phase transition), d) Transfer of the concepts to different phenomena from biological and social science disciplines. Teachers provided some examples related to environmental and social networks problems to illustrate the transference possibilities. Integration and transfer of knowledge was evaluated through a questionnaire of five scaling questions and three open-ended questions that need further explanation administered before and after the intervention and compared using Student's T-test and effect size (Cohen's d) was calculated. Student's abilities of transfering knowledge between social and biological phenomena increased ($t= -4.14$; $p<.001$) with a medium effect size ($d=-0.51$). After the intervention, 40% of students were able to relate phenomena of social and natural sciences, 14% could relate environmental and personal relationship problems, and 22% were able to relate a personal experiences with technological and social processes. The intervention was rated as highly satisfactory by students and teachers, and showed effectivity for developing integration and transfer of knowledge in highschool students.

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Acute Effects Of Various Noise In Differential Learning During Rope Skipping On Brain And Heart Synchronization Using Cross Fuzzy Entropy

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Introduction:

Neural and physiological effects of physical activity, depending on type, intensity and duration, are attracting increasing interest. The various influences on brain or cardiac function, however, are usually studied separately and modelled linearly. Limitations of these models are now leading to a rapidly growing number of studies based on nonlinear models, whose advantages lie in their more appropriate application to nonstationary signals with higher computational efficiency, and the identification of nonlinear properties. Nevertheless, little is known about the underpinning neuro-physiological synchronization induced by different motor learning approaches. The purpose of this study was to investigate the acute effects of a single bout of rope skipping on the interaction of brain and heart signals using cross fuzzy measure entropy (C-FuzzyMEn) and whether these depend on different noise levels, within the framework of differential learning theory.

Methods:

Thirty-two healthy male right-handers (27.3 ± 4.7 years) were randomly and equally distributed to one of four rope skipping conditions with similar cardiovascular (measured by heartrate) demand: differential learning condition with a new instruction every second, every ten seconds, every twenty seconds and repetitive learning. Each subject performed a single bout of rope skipping for three minutes in respect to the specific motor learning condition. Electroencephalography (EEG) and electrocardiography (ECG) were measured simultaneously at rest before and immediately after physical exertion for 25 minutes. After data pre-processing, time signals were bandpass filtered for the calculation of C-FuzzyMEn between the signal of specific EEG frequency bands (theta, alpha, beta, gamma, total spectrum) and ECG. All C-FuzzyMEn data were normalized to the individual resting phase before exercise.

Results:

EEG frequency band and brain area specific significant changes in C-FuzzyMEn were found depending on noise level of the specific rope skipping condition. Both acute effect and recovery analysis showed different trends of C-FuzzyMEn depending on EEG frequency band and brain area over time.

Discussion & Conclusion:

Conducting rope skipping with varying degrees of movement variation appears to affect the synchrony between cardiac and brain signals during the recovery phase. Because of the importance of this interaction for recovery in general, these findings give enough incentives to reconsider the philosophy of classical endurance training.

Dynamical Individual Processes In Sports: Evidence For Non-ergodicity In Load And Recovery

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Purpose: Dynamical systems theorists argue that the existence of a common or (group) average is a fallacy due to individual variability typically observed in human subjects (Den Hartigh et al., 2018; van Geert, 2011). To date, however, studies in the sports sciences, and load and recovery in specific, are typically conducted at the group-level, although they aim to enhance our understanding of individual processes (Glazier & Mehdizadeh, 2019). It is highly questionable whether group-level results generalize to individual processes. Hence, the aim of the present research is to examine to what extent group-level statistics can be generalized to individual athletes, which is referred to as the "ergodicity issue" (Molenaar & Campbell, 2009; van Geert, 2011). Non-ergodicity may have serious consequences for the way we should analyze, and work with, load and recovery measures in the sports field.

Methods: On a daily basis, we collected internal training load (RPE*training duration) and recovery (TQR) data across two seasons among youth male football players, and analyzed the measures on both the group- and the individual-level.

Results: Group- and individual-level analysis resulted in different statistical outcomes, particularly with regard to load. Specifically, standard deviations within individuals were up to 7.63 times larger than standard deviations between individuals. In addition, at either level, we observed different correlations between load and recovery.

Conclusions: The results suggest that the process of load and recovery in athletes is non-ergodic. Recommendations for training programs of individual athletes may be suboptimal, or even erroneous, when guided by group-level outcomes. The utilization of individual-level data is key to ensure the optimal balance of individual load and recovery. In line with the dynamical systems theory, researcher should therefore shift the focus from analyzing relationships between variables on the group-level, to the analysis of dynamical processes on the individual-level.

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Adaptive Capacities and Complexity of Heart Rate Variability in Patients with Chronic Obstructive Pulmonary Disease Throughout Pulmonary Rehabilitation

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Introduction. The complexity of bio-signals, like heart rate variability (HRV), is considered to reflect adaptive capacities of the organism [1]. In Chronic Obstructive Pulmonary Disease (COPD) patients, response to pulmonary rehabilitation (PR) and exercise tolerance are typically assessed by the 6-minute walk test (6MWT). Both 6MWT distance and complexity of resting HRV have been shown to increase with PR [2]. Our aim is to investigate whether HRV complexity at rest and during 6MWT contains information as to the adaptive capacities in COPD patients, and their putative evolution during PR. If complexity reflects adaptive capacities, one could expect that complexity of HRV at the start of PR would relate to the improvement in 6MWT distance over PR, and that it would be decrease between 6MWT and rest condition, and improve in association with 6MWT distance over PR.

Method. Twenty-three COPD patients (64±8 years, with forced expiratory volume in 1s of 55±19% predicted) were tested three times at start (T1), middle (T2) and end (T3) of 4 weeks PR. Each time, the 6MWT distance, and HRV at rest and during 6MWT were measured. The complexity of RR interval series was assessed by evenly spaced Detrended Fluctuations Analysis. The fractal exponent α (level of complexity) and $|1-\alpha|$ (deviation from maximal complexity) were submitted to statistical analyses.

Results. The 6MWT distance was significantly increased at T2 and T3 compared to T1 ($F(2,44) = 38.2$; $p < 0.05$, $\eta^2 = 0.11$). Neither α nor $|1-\alpha|$ at rest and during 6MWT changed significantly during PR, nor were they associated with 6MWT distances at the three times ($p > 0.05$). During the 6MWT, α and $|1-\alpha|$ were significantly lower compared to rest throughout the PR ($F(1;21) = 5.28$, $p = 0.04$, $\eta^2 = 0.04$, $F(1;21) = 4,81$, $p = 0.03$, $\eta^2 = 0.03$). The level of α during 6MWT at T1 was positively correlated with the improvement of 6MWT distance over PR ($r(1,23) = 0.44$, $p < 0.05$).

Discussion. The complexity does not appear to represent functional capacities. The presence of association between complexity at the start of PR and the increase in 6MWT distance seems consistent with the notion that complexity reflects the adaptive capacities [3]. Further studies should examine the information carried by physiological complexity on different facets of the adaptability of the organism.

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Time-Variability of Muscle Oxygen Saturation During Graded Maximal Exercise

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The time-variability structure of some kinematic and physiological variables during exercise has revealed its potential in the early detection of acute fatigue (Gronwald et al., 2019; Vázquez et al., 2016). However, the monitoring and diagnostic possibilities of analyzing the time series dynamics of physiological variables, and in particular, the muscle oxygen saturation is still unexplored. This study aimed to compare the time-variability structure of muscle oxygen saturation at the beginning and the end of a progressive and maximal exercise. Nineteen participants (11 females, 8 males; 21.00 ± 2.29 y.o.; 1.71 ± 0.07 m; 64.57 ± 10.06 kg) performed a graded maximal running test, starting at 8 km/h an increasing 1 km/h every 100 s until exhaustion. The tissular saturation index (TSI) from their quadriceps was continuously recorded during the test at a sample frequency of 10 Hz (PortaMon, Artinis, Medical System). Detrended Fluctuation Analysis (DFA) and Sample Entropy (SampEn) were used to detect the time-variability structure of the initial and final 2048 TSI data points. These initial and final portions of exercise were afterwards compared using the Wilcoxon test. The results showed that the Hurst exponent of the TSI decreased (from $H = 0.69$ at the beginning to $H = 0.49$ at the end of the exercise, $Z = -3.62$, $p < 0.01$); while SampEn increased (from 1.31 to 1.81; $Z = -3.70$, $p < .01$). A higher variability of TSI towards an un-correlated white-noise with fatigue was found approaching exhaustion. Gronwald et al. (2019) found similar heart rate variability dynamics during an incremental maximal cycling exercise. Such tendency towards a merely random noise close to exhaustion may reflect a complexity reduction of the regulatory mechanisms of muscle oxygen concentration and a progressive loss of physiological adaptability to workloads during progressive maximal exercise tests. Further research is warranted to explore the multilevel network interactions involved in this TSI change of dynamics. In conclusion, our findings suggest that the time-variability structure of muscle oxygen saturation is sensitive to acute fatigue during exercise.

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Use Of Machine Learning Techniques And Bayesian Network In Return-To-Sports With A Complex Systems Approach

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Introduction

There is a growing recognition most sporting environments are complex adaptive systems. This acknowledgement extends to sports injury, and is reflected in the individual responses of athletes to both injury and return-to-sports (RTS) protocols. The complex systems approach provides a theoretical framework for interpreting the patterns that emerged from biopsychosocial and other external factors. However, the high degree of interlinks, independencies, and temporal components have made it very difficult for practitioners to apply complex systems theory in practice. To affirm the practical utility of the complex systems approach in applied settings and facilitate a paradigm shift, analytical tools that could operationalize the complex systems approach is required.

Discussion

Machine learning and Bayesian network analyses are all potential tools for modelling complex systems. These methods consider the dynamic interaction at multiple levels simultaneously, consequently viewing RTS more completely.

Machine learning is a subfield of artificial intelligence (AI), where the computer system learns from data, without being explicitly programmed to do so [1, 2]. The goals of machine learning techniques in sports medicine setting can be divided into predictive and descriptive modelling. Specifically, predictive modelling can be used for injury prognosis, diagnosis, and rehabilitation planning. Descriptive modelling can be used to characterize the general property of an injury, such as its severity, as well as include hypotheses of causality. There are four major approaches (i.e., association, classification, clustering and relationship modelling) that could support RTS decisions.

Bayesian methods are becoming increasingly popular in the study of sports [3]. It is useful for addressing the uncertainties in RTS decision making and provide a relatively simple structure. Bayesian network (BN) uses Bayesian inference for probability computations and can be visually presented using directed acyclic graphs (DAG) [4]. These show how various discrete or continuous factors influence one another by a graphical presentation. To specify the probability distribution within the network, prior probabilities of all root nodes are required. BN allows calculation of the conditional probabilities of the nodes in the network when the value of some of the nodes have been observed.

Conclusion

The complex systems approach has been applied to understand different aspects of sports science and medicine. Practitioners should be critical to the result of discrete RTS tests when assessing the information for RTS decisions to avoid missing out on the full picture. Moving forward to the operational level, the use of computational and simulation-based techniques such as machine learning and Bayesian network should be considered.

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In Team Sports More Is Different

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In team sports there is a tacit assumption that team performance is a product of the sum of individual players' performance. Clubs seek to recruit the best players and sport academies aim to create stars to form competitive teams. However, exceptional properties which cannot be equated to any single player, emerge in teams sharing common goals (Torrents et al., 2021).

Based on the cooperative-competitive intelligence (CCI) theory, the principles of complex systems science, and theories of biological evolution, this contribution aims to update the training goal and the methodological criteria of training processes in team sports. According to the CCI theory (Hristovski & Balagué, 2020), the classical training goal of enhancing the player's psychomotor and athletic abilities in isolation is replaced by the general aim of developing the team functional diversity/unpredictability (D/U) potential. Underpinned by the properties of nestedness and circular causality of constraints, the D/U potential is better developed intervening at the upper level, that is, the team level, which has been conceptualised as the main training unit (Pol et al., 2020). Due to the nestedness of constraints, the intervention at team level triggers reorganisations at lower embedded structures (players and their subsystems) in a correlated way. As circular causality integrates all dimensions and levels (bottom-up and top-down), there is no need to train separately players' technical, tactical and athletic abilities. It seems more effective to constrain the team with meaningful competitive-cooperative challenges because this will, in turn, constrain all components and processes of lower levels in a correlated way (Balagué et al., 2019). At the same time, due to the circular causality property, competitive teams will emerge spontaneously from individuals sharing common values and goals challenged by meaningful environmental constraints.

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Handball: Performance Indicators Are Dynamic

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The search for performance indicators is an issue that has concerned, and continues to concern, researchers and handball coaches. Knowing what technical, tactical and physical behaviors differentiate winners from the losers' teams, can be very useful in the design of training programs and in the planning of the competition. Traditionally, performance indicators have been obtained after analyzing the behavior of the matches played in a given tournament, reflecting, therefore, a stable and static performance.

However, according to the dynamic and non-linear nature exhibited by complex systems, such as handball teams, the behaviors carried out throughout a competition are not stable. Teams do not play the same way every game: each rival has different strengths and weaknesses; the pressure is not the same in a preliminary round as in a semi-final; the form of the players changes throughout the tournament, etc. These and other factors determine that the behaviors that are successful in one match do not have to be successful in another.

Variability is part of sports performance, the best handball players exhibit more flexible and adaptive behaviors than lower-level ones, who tend to offer more stereotyped behaviors. Variability can be understood as the performance of different behaviors to achieve the same goal, such as overcoming a defensive system, and, also, as the ability to adapt a certain action to unexpected changes that occur in the sports context, such as the movements of rivals or teammates.

The objective of this work was to find performance indicators of the Netherlands women's national handball national team during the 24th IHF Women's World Championship, Japan 2019, where it was champion. Using a follow/idiographic/multidimensional technique design, six matches were studied (final, semi-final and four matches from the main round). An ad hoc observation instrument was designed and was input into the Dartfish 5.5 program, which was used as the recording instrument. The HOISAN 1.4 program was used for the polar coordinate analysis, which demonstrated the emergence of different offensive behaviours patterns in every match.

The results found indicate different patterns of behavior in each of the matches analyzed. These results show, in part, the variability of the behaviors carried out by the world champion team throughout the tournament and emphasize the need to use tools that allow knowing the dynamic nature of the performance indicators.

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The Effects Adding Tactical Variability on Youth Players' Performance During Association Football Small-sided Games

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Performance in association football results from the players ability to interact with the surrounding information to unfold goal-directed behaviours (Coutinho et al., 2019). Under this perspective, inducing variability during training practices seems to foster players' ability to couple their actions to the information, while also promoting adaptive movement patterns (Santos et al., 2018). Despite that, most research has been focused on interventions, and less is known regarding how players acutely adjust their behaviour while performing tasks with additional variability. Thus, this study intended to explore the effects of playing with additional tactical variability in youth football players' physical, and positional performance. Twelve youth football players performed a Gk+6v6+Gk game under two conditions: (i) perform under 1:2:3:1 formation (control condition, CTR); and (ii) perform under different playing formations modified on each minute (tactical variability, TACT). Players' positional data was used to compute time-motion and tactical-related variables. From the positional perspective, there was an increase in the players space exploration index (~ 9% more, $p < .05$, small effects) during the TACT, while lower lateral synchronization (~6% less, $p < .05$, moderate effects) compared to the CTR. Players covered more distance while running (~38% less, $p < .05$, small effects) and sprinting (~56% less, $p < .05$, small effects) during the TACT than the CTR. Considering that players were required to perform under different playing positions and structures during the TACT, it is likely that it contributed to the higher space explored (e.g., a midfielder may have to play during 1-min as striker, and in other min as wide midfielder), and consequently higher physical demands. Usually, players are more synchronized in the longitudinal plane as result of being the most prominent direction of play (Coutinho et al., 2019), thus decreasing the lateral synchronization may have resulted as a strategy to allow the players maintain proper levels at the longitudinal direction. The results showed distinct movement patterns between conditions that reflect the players' ability to

adapt to the additional variability. From practical perspective, using the TACT condition may enhance the players ability to perform as result of local information (e.g., distance between players, numerical relation) and less dependent on playing structures.

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Keeping The Goal Safe! Measuring Synergistic Behavior In A Defensive Unit Of A Football Team

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In team sports, teammates formed functional synergies as they struggle over the hegemony on each sub-phase of a match. Usually studies on interpersonal coordination have study this process by dyads, thus there is the need to measure collective behavior that has more than two players involve. With this purpose, in the current study the Uncontrolled Manifold (UCM) hypothesis was used to measure the behavior of a defensive unit formed by four defenders (LB, LCB, RCB, and RB) during a set 60 Successful and 38 Unsuccessful situations selected over five competitive matches. Successful situations were conceptualize as sub-phases were the defensive unit recover the ball while Unsuccessful situations were defined as the sub-phases were the attacking team got a shot to the goal, a goal, or a penalty. The selected performance variables were related with the average position of the unit (described by the Centroid) and its structure (Stretch Index). Successful sub-phases were associated with lower values of UCM), meaning the performance variables were under less control than in unsuccessful attacking situations. Thus, successful movement of the unit may be related to an effective management of its variability rather than the limitation of this variability. Furthermore, the longitudinal direction was under tighter control than the lateral direction, which could be related to the unit trying to keep in line exploiting the offside rule. Finally, the unit controls its structure (stretch index) more than its average geographical position (centroid), meaning that synergies are formed stronger and more commonly in order to keep certain distribution over the field than its actual position. Thus, we successfully employ the UCM method to measure the synergistic behavior of a defensive unit in a multi-player level, rather than coupling players into dyads.

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Exploring How Manipulating The Number of Creative Players in the Opposing Team Impacts Youth Football Players Performance

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Sports coaches consider creativity a looked-for feature. Although creativity has been signaled as exceptionally essential, proper enriching trainings situations should be carefully designed (Santos et al., 2018). Earlier studies demonstrated that training tasks must require an appropriate level of difficulty to trigger creative behaviors (Torrents et al., 2016). A reasonable approach to promote different challenges for youth players might be through the manipulation of the level of creativity in the opposing team. Thus, this study explored how changing the number of creative opponents during a small-sided game (SSG) situation affected the physical, creative, and tactical performance on U11 football players. Firstly, a total of 20 players (U11 n=20) were tested during SSG to rank their individual creative potential. Thereafter, were selected the 4 most highly creative players and 7 intermediate players. The team under analysis (control team) was composed of 4 intermediate players that were kept constant across the data collection. This team competed against a different number of creative opponents during the following SSG (Gk+4x4+Gk) scenarios: a) playing against 3 intermediate players and 1 creative player (1C); b) against 2 intermediate and 2 creative players (2C); c) against 1 intermediate and 3 creative players (3C); and finally, d) against 4 creative players (4C). Overall, playing against more creative opponents led to an increase in the variability ($p = .002$) and regularity ($p < .001$) in the distance to the nearest teammate. When facing more creative opponents, it is likely that the control team spend more time defending which would justify the adoption of more regular behaviors. The decrease in the total distance covered ($p = .017$) and increase of walking distance ($p = .013$) when facing more opponents strengthen this evidence. In addition, there was a decrease in the number of shots-on-target ($p = .036$) against 3C and 4C. From creative components, playing against 1C induced more fluent actions compared to 2C and 3C (small effects), while emerged higher versatility values in 2C and 3C compared to 1C (small to moderate effects) and original actions were found against 1C. Interestingly, it seems that youth football players perform novel/rare and different actions in low to moderate demanding scenarios. Ultimately, playing against a team full of creative players suppress all the related components. Therefore, the study findings may assist coaches in design more appropriate and challenging environments to develop youth players creativity.

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