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Editorial: Nonlinear dynamics and networks in sports

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Evolution, self-organization, synchronization, entropy, or chaos are traditionally related to statistical physics and applied mathematics. Although their early developments came up from systems exclusively of these branches of knowledge, the applications of the methodologies quantifying the appearance of such phenomena in other real systems are increasing from year to year. Among these, Sports Science is one of the beneficiaries of the high applicability of Complexity Sciences. This fact is becoming more evident due to the recent ability to capture a diversity of new variables thanks to new technological advances. In this way, it is possible to record the speed of a ball during a tennis match, the strokes' position, the distances ran by each player and the corresponding velocities. In team games, such as football, we can track the position of the twenty-two players and the ball at a resolution of 25 frames per second, which results in large datasets containing priceless information about each team (and player) style of playing. However, how to extract useful information from such large datasets? The answer is not simple and, on the contrary, it implies an analysis based on the complexity of the systems under study. Furthermore, it requires the effort of mathematicians, physicists, data-analysts and sports scientists united in a common framework in order to adapt classical (and not so classical) methodologies coming from nonlinear dynamics [1] or network science [2] to the analysis of sports. Despite there is a vast literature about nonlinear analysis of sports datasets, recent advances in such fields, such as multilayer networks [3], chimera [4] or Bellerophon states [5], explosive synchronization [6] or controllability of networks [7] (to mention a few) make necessary a new revision of how sports science can benefit from them.

Specifically, the current Special Issue is focused on the use of nonlinear dynamics and networks models in order to improve the knowledge and practical applications about teams and athletes/players' performance during trainings and competitions.

The Special Issue opens with two papers about racket sports: Tennis and Badminton. Giménez-Egido et al. [8] compared two scaled competition formats for under-10 years (U-10) tennis players analyzing serving performances. Twenty players played 40 matches according to the International Tennis Federation's Tennis guide for U-10 players in the stage green (GC) and 40 matches in a modified competition (MC) decreasing net height (from 0.91 m to 0.80 m) and court size (from 23.77 m x 8.23 m to 18.00 m x 8.23 m) with green ball (lower compression ball). Their statistical approach showed a nonlinear trend between contexts with increased performance in first serve success (more aces and unreturned serves) in MC than GC. Authors suggest that nonlinear approaches should be considered during formative stages in youth tennis players where reducing net height and court-size improves the serve performance. On the other hand, Gómez et al. [9] showed how Network Science could be applied to identify the style of playing of badminton players. Specifically, the authors constructed

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badminton stroke networks, consisting of directed bipartite graphs whose nodes are spatial positions of the court connected through directed-weighted links accounting for the number of times the shuttlecock goes from one position to the other. The properties of the one-mode projections of the bipartite networks were analyzed and related to a player's specific style, showing that both the player and the rival must be considered in the analysis.

Basketball is another sport that has been traditionally analyzed under the scope of nonlinear dynamics and complexity sciences. Petersen et al. [10] proposed the use of a novel methodology to better capture the players' performance in an objective and unbiased viewpoint, which can be applied to different eras. The authors showed that, using a renormalization technique, it is possible to extract seasonal performance metrics. The method was applied to recovered data from Major League Baseball and National Basketball Association showing that the functional form of the distribution of career achievement is preserved at the season and career level. An appropriate renormalization of metrics that account for players' achievements can be used to compare players among several dimensions like season lengths, team strategies, as well as for different sports.

However, football is the sport that has benefited the most from this kind of approach, being the core of the Special Issue. Gómez et al. [11] and Li et al., [12] showed that team performance is more than just the performance of individual players. In particular, Gómez et al. [11] examined winning and losing teams' performances during the four different match-status periods that occur in close soccer matches' comebacks. Specifically, they used a nonlinear analysis of the relative-phase obtained from the exchange of the ball possession between teams. Shots, passing effectiveness and ball possession performances were analyzed in 17 matches of the Spanish professional soccer league. Interestingly, the results revealed shifts from anti-phase to in-phase relations depending on variables such as the shot or passing effectiveness.

On the other hand, Li et al., [12] analyzed 1200 games from 2014-2018 Chinese Super League and applied a Linear Support Vector Classifier (LSVC) to the ranking of teams and exploitation of key performance features concerning match outcome. They analyzed different game outcomes (win vs. not-win) with LSVC and calculated a weight for different performance features. The weights showed that shots on target, pass success, saves, interceptions, clearances and tackles were important positive features. In contrast, opponent shots on target, passes, bad shot rate, crosses and red card were features that had a great negative impact. Finally, a team rank expressing the teams' performance was built.

The understanding and modeling of team and player dynamics have been the main focus of three papers of the Special Issue. López-Felip and Harrison [13] analyzed the dynamics of a player when keeping the ball possession and progressing with it. To do that, players of a team either keep passing the ball around or dribble it. The authors proposed a two-stage model to capture instances in which football players dribble the ball around the field. The model consisted of a "touch" event, an end-directed projectile launch, and a "go" phase, during which the ball follows its projectile course and the player performs locomotion toward the moving target of the ball. Adjusting parameter values, such as touch velocity, the model could be used to analyze how dribblings respond to the context of the game.

Marcelino et al. [14] went one step beyond by analyzing the coordination of players' dynamics. They analyzed the collective motion patterns exhibited by football players in order to understand the collective strategies associated with team performance. Authors identified collective dynamics that characterize winning and losing teams by analyzing pairwise relationships among all the players using spatiotemporal correlation functions. They also found different players' behaviors and interactions, allowing them to assign a unique behavioral pattern for each individual and team.

Furthermore, Clemente et al. [15] were concerned about the dynamics of players during training. They carried out a review about small-sided soccer games (SSGs), which are useful to reproduce specific collective dynamics with a small number of players, different formats, or pitch sizes to replicate certain dynamics of a real game. In this review paper, the authors provided new insights comparing different game factors. Specifically, authors focused on five topics related to tactical and collective behaviors: the effects of different game formats; the effects of different pitch sizes and configurations; the effects of task adjustments; the effects of age and competitive and expertise levels; and multidimensional effects.

Notwithstanding, Network Science and its application to football analysis have captured the most attention of scientists participating in this Special Issue. Last years have witnessed a diversity of papers showing how translating team dynamics into networks could lead to new insights about the performance of football players and teams [16]. Six papers of the Special Issue contributed to enlarge the state-of-art of this new approach.

Clemente et al. [17] used event datasets from the 2018 FIFA World Cup, built the corresponding player passing networks (where nodes are players and edges are passes between them), and analyzed the variations of the player centrality. Next, they investigated the interplay between centrality and the match outcome. Interestingly, the authors found different levels of correlations between prestige (amount of inbound passes) and the player's positions. Comparisons of passing network centrality levels between match outcomes were also reported. Thus, match outcome (and possibly scoring status during the match) was somewhat related to the passing centrality of various playing positions.

Wu et al. [18] studied the social network in football using player's positions and passing sequences. The results of this network approach showed that midfielders are the key position during the passing process, followed by central defending midfielders. This network analysis allowed obtaining the passing patterns related to playing positions and the success of passing sequences.

Sarmento et al. [19] studied the attacking phase of a football team by combining Network Science parameters and the opinion of two technical staff members: the head coach and a performance analyst. Two kinds of networks were analyzed: (i) pitch-networks, where nodes are different areas of the pitch (3x4) and (ii) player networks, where nodes are football players. Different network parameters were extracted to characterize the organization of the whole team but also to assess the importance of certain pitch regions and specific players. Finally, the opinion of the two members of the technical team allowed interpreting the results obtained and introduce some explanation about the role of the team's key players.

Herrera-Diestra et al. [20] investigated the particular organization of Guardiola's F.C. Barcelona (FCB) during season 2009/2010, using datasets from the Spanish National League *"La Liga"*. They constructed and analyzed FCB's pitch networks, performing a multi-scale analysis focused on evaluating pitch networks' properties at different scales (i.e., at different partitions of the pitch). For each scale, a diversity of network parameters of FCB and its opponents were calculated. Results showed how, depending on the spatial scale, there are statistically significant differences between FCB and the rest of the Spanish league teams.

Ramos et al. [21] transformed the spatial coordinates of players into simplicial complexes [22], where links were created according to the proximity between a group of players. In this way, authors established sets of players forming different kinds of simplices representing n-ary spatial interactions. They demonstrated that the scaling properties in the frequency of occurrence of players' sets exhibit a Zipf-Mandelbrot regularity. This work also gen-

eralized how the sets Goalkeeper and Goal drove the exceptions of that regularity, unveiling some design in the players' configuration that could be associated with a match strategy.

Finally, Medina et al. [23] presented a method combining a simple regression model and complex network features to assess the probability of teams to win/loss/tie matches when playing home or away. They showed that the addition of both approaches could offer useful information in determining matches outcomes. To validate their conclusions, they used data from the Spanish national league *"La Liga"* during season 2012-2013 and observed that, in particular, betweenness centrality was the most informative parameter when evaluating performance during the tournament.

Given all contributions of this Special Issue, we are confident that the application of nonlinear dynamics and network science to analyze sports is an emerging field with promising perspectives that, in the years to come, will provide a complementary point of view to classical analysis about team and player/athlete performance.

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