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Integrating Constraint-led and Step-Game approaches to develop sport performance: a season-long action-research study of a youth volleyball team

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“As pessoas que eu mais admiro,

São aquelas que nunca acabam”

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Resumo

A presente dissertação procura examinar a influência da combinação de uma abordagem ecológica (i.e., abordagem guiada por constrangimentos) com uma abordagem construtivista (i.e., abordagem progressiva ao jogo), através de um desenho de investigação-ação no qual o investigador assumiu o duplo papel de treinador-investigador, no desenvolvimento da performance desportiva de jovens jogadoras de voleibol ao longo de uma época competitiva. O carácter cíclico e interventivo da investigação-ação possibilitou a monitorização sistemática e contextualizada de variáveis de processo (i.e., conhecimento tático) e de produto (i.e., tendências de sincronização coletivas em ambiente competitivo), facilitando, portanto, a inter-relação entre a informação proveniente do treino e da competição. Ademais, dada a natureza interpretativa deste projeto de investigação, foi possível compreender o impacto que o uso de diferentes estratégicas pedagógicas característica de ambas as abordagens (p.e., aumento complexidade tática via manipulação de constrangimentos, questionamento) tiveram no desenvolvimento da performance desportiva das jogadoras, em cada momento da época. A evolução do processo ensino-aprendizagem foi captada através de um diário reflexivo, notas de campo, reuniões de grupo focal, e documentação dos planos de treinos e de jogos. As coordenadas posicionais das jogadoras foram obtidas através do software TACTO, e utilizadas para aferir acerca do desenvolvimento das tendências de sincronização coletivas pelo cálculo do método de fase-cluster. O uso combinado das duas abordagens, revelou-se benéfico para a evolução do conhecimento tático, bem como para o desenvolvimento das tendências de sincronização coletivas em competição. Em particular, o aumento da complexidade tática: (i) induziu um progressivo aumento do conhecimento tático (i.e., consciência tática, atenção focal, e pensamento estratégico); (ii) atuou como ruído, promovendo diminuição da sincronia da equipa a curto-prazo, mas um reaumento a longo-prazo.

PALAVRAS-CHAVE: PEDAGOGIA DO DESPORTO, ANÁLISE DA PERFORMANCE, INVESTIGAÇÃO-AÇÃO, ABORDAGEM CENTRADA NO AMBIENTE E NO JOGADOR, VOLEIBOL.

Abstract

The aim of the present thesis was to examine the influence of combining an ecological approach (i.e., constraints-led approach) with an constructivist approach (i.e., step-game approach), using an insider action-research design where the researcher assumed the dual role of coach-researcher, on the development of sport performance in youth female volleyball players over a competitive season. The cyclical and interventive nature of the action-research design allowed for the systematic and contextualised monitoring of process variables (i.e., tactical knowledge) and product variables (i.e., collective synchronisation tendencies within competitive environment), thus facilitating the interplay between information from training and competition. Moreover, because of the interpretative nature of this research project, it was possible to comprehend the impact of using different pedagogical strategies with characteristics of both approaches (e.g., increasing tactical complexity via constraints manipulation, questioning) on the development of players' sport performance at each moment of the season. The evolution of the coaching-learning process was captured using a reflexive diary, field notes, focus group interviews, and by documenting training and game plans. The players' positional coordinates were collected using TACTO software and used to measure the development of collective synchronisation tendencies via the cluster-phase method calculation. The combined use of both approaches had benefits for evolving tactical knowledge, and for the development of collective synchronisation tendencies in competition. In particular, the increasing of tactical complexity: (i) induced a progressive enhancement of tactical knowledge (i.e., tactical awareness, attentional focus, and strategical thinking); and (ii) acted as noise, causing a decrease in team synchrony in the short-term, but a re-achievement in the long-term.

KEYWORDS: SPORT PEDAGOGY, PERFORMANCE ANALYSIS, ACTION-RESEARCH, PLAYER- AND ENVIRONMENT-CENTRED APPROACHES, VOLLEYBALL

List of Abbreviations

CLA – Constraint-led Approach

SGA – Step-Game Approach

AR – Action-Research

PE – Physical Education

CEK – Coach's Experiential Knowledge

CAD – Coaching for Athlete Development

CCP – Coaching for Competitive Performance

SSCG – Small Sided and Conditioned Games

CPE – Competitive Performance Environment

CPM – Cluster-Phase Method

TK – Tactical Knowledge

RD – Reflexive Diary

FN – Field Notes

FG – Focus Group

DLT – Direct Linear Transformation

TEM – Technical Error of Measurement

SMD – Standardised Mean Differences

ST – Synchronisation Tendencies

dofs – Degrees of freedom

List of Formulas

Cluster phase time-series of the team in complex form:

$$\acute{r}_A(t_i)\frac{1}{n_A}\sum_{k\in\Gamma_A}\exp(i\theta_k(t_i))$$

Cluster phase time-series of the team in radian form:

$$\overline{\emptyset}_A(t_i)\; atan2(\,\acute{r}_A(t_i))$$

Continuous degree of synchronisation of the team:

$$\rho_{\Gamma_A}(t_i) = \left|\frac{1}{\mathrm{n}_A}\sum_{k\in\Gamma_A}\exp\,(i(\theta_k(t_i)\;\overline{\emptyset}_A(t_i)))\right|$$

Temporal mean degree of team synchronisation:

$$\rho_{\Gamma_A}\frac{1}{T}\sum_{i=1}^{T}\rho_{\Gamma_A}(t_i)$$

Chapter I: Introduction

1.1 Rationale

For decades the analysis of sport performance - founded on the traditional idea that expert sport performance requires athletes to excel in physiological, technical, tactical and psychological domains - has incited the interest of various actors within the field of sports (e.g., athletes, technical-staff, researchers, fans, etc.) (Janelle & Hillman, 2003). From a scientific viewpoint, the large number of published books, special journal editions and systematic reviews demonstrates how academics have attempted to evolve training processes as a means to improving competitive performance (Hughes et al., 2019; Kolman et al., 2019). Despite the long-established view that a deep information exchange, and interplay, between training and competitive contexts is favourable (for instance, grounded on specificity principle[1]), the analysis of sport performance has typically examined training and competitive performance separately. This systematic decomposition of sport performance analysis has provided useful insights about performance outcomes (e.g., by evaluating and comparing a set of players' skills before and after the interventional protocol), but has also limited our understanding about the processes inherent to its holistic development (e.g., Silva et al., 2014). In this sense, it is crucial that new scientific investigations consider the analysis of sport performance in both environments (training and competition) using an integrated approach, once the way that players and teams prepare to compete (i.e., training process) must be aligned with the competitive demands, and vice-versa.

To achieve this outcome, however, it is necessary to consider the nature of each individual sport, and to identify the relevant technical-tactical competitive constraints so that the design of learning tasks can encompass such specific requirements. In this respect, the competitive demands for team sports means there is a need of players who are tactically aware, autonomous, critical thinkers and active decision-makers, and who understand the dynamical logic of play instead of merely reproduce highly structured and uncontextualized techniques. These contemporary competitive demands require that sport practitioners (e.g.,

[1] The design of learning tasks with technical-tactical demands similar to the competition will increase the odds of a successful sport performance within competitive environments (Henry, 1968).

teacher, coaches, etc.), move from coach-centred to player-centred approaches (Hastie & Mesquita, 2016; Mesquita et al., 2012). Specifically, the coach-centred approach, which is characteristic of the behaviouristic paradigm where the autocratic teaching style is common, places the coaches at the ‘centre-stage’ and considers players as motion reproducers and, therefore, emphasises the mass reproduction of technical skills (Lee, 1993; Mosston & Ashworth, 1990).

In contrast, the player-centred perspective adopts a constructivist lens. According to this paradigm, learning is an individual process dependent on the players taking responsibility to learn, in which knowledge is built upon the contrast between previous experiences and what is being experienced at a particular moment (Chandler & Mitchell, 1991; Vygotsky & Cole, 1980). In this sense, the players’ learning development begins (and ends) in the player, once an experience only acquires a meaning when is interpreted by his/her (Brown et al., 1989). By underlining the relevance of players’ knowledge construction, this perspective highlights the tactical domain, which is currently extensively demanded in competitive performance environments. Furthermore, making players central to the teaching-learning process usually favours democratic styles of teaching (Mosston & Ashworth, 1990).

Given the current need to develop players who are tactically aware, technically versatile, and endowed with a critical thinking abilities, the constructivist paradigm currently occupies a prominent place in teaching approaches, both theoretically and practically (Roberts & Potrac, 2014). From a theoretical perspective, the use of constructivist lenses implies that the development of players’ tactical knowledge is influenced by experience. Hence, the authenticity of the experience (i.e., learning task environment) becomes essential for players apply previous knowledge and reconstruct it into new understandings. From a practical and interventionist standpoint, the coach is challenged to rethink their own pedagogical practices to simplify learning processes and optimise performance enhancements. In doing so, coaches take the role of *facilitators* (Dyson et al., 2004), *sport-ecology-designers* (Woods et al., 2020), and/or *designers of learning* (Roberts et al., 2019), in that they are responsible for designing learning scenarios in which players are confronted with problem-solving game situations, and invited to explore valuable technical-tactical solutions.

The development of players' tactical knowledge (TK) has been endorsed in the literature as a means to deal with the dynamic, complex and unpredictable nature of competitive environments (McPherson & Kernodle, 2003; McPherson & MacMahon, 2008; Perla et al., 2016). Specifically, TK refers to the decision-making processes underlying the organisation of functional and tactical behaviours when players interact so that they can self-regulate and self-organise to overcome the performance constraints (McPherson & Thomas, 1989). Knowledge *of* the performance environment helps support players' learning and performance in sport by facilitating the construction of intrinsic relationships between knowledge, perception, and action (Araújo et al., 2019). In turn, knowledge *about* the environment helps support verbal problem-solving and decision-making via the perception of language, symbols, and instructions (Gibson, 1966). Despite its relevance, a small number of studies have examined the processes inherent to the development of players' TK. These few investigations have mainly focused on assessing the impact of different pedagogical approaches on its enhancements (e.g., Harvey et al., 2020). As previously stated, the effectiveness and appropriateness of pedagogical processes in training contexts requires, firstly, a recognition of the competitive environment ecology. Hence, the development of players' TK implies the deepening of tactical understanding by engaging and practicing within specific meaningful and representative learning scenarios over extended time-periods.

The representative design, a concept originally proposed by Brunswik (1955), advocates, in application to sport sciences, the need to ensure that the constraints introduced in practice learning tasks suitably represent competitive performance environments so that players can identify and perceive the key information sources and action opportunities within those particular settings (Pinder et al., 2011). By doing so, the interplay between training and competition is guaranteed, with the mutual and cyclical relationship among knowing (tactical skills) and doing (technical skill) being progressively engaged and facilitated. The ecological and representative design of learning tasks has mostly been addressed by the Constraint-led Approach (CLA) (Davids & Araújo, 2005).

Built upon concepts from dynamical system theory, ecological psychology and ecological dynamics, the CLA seeks to understand how players and teams adapt their tactical behaviours as a function of the interacting task, individual and environmental constraints (Davids et al., 2008). Here, constraints are defined as boundaries that shape the emergence of movements/behaviours (Newell, 1986), and provide opportunities for individuals to *act in* and *interact with* the environment (i.e., affordances (Gibson, 1979)). Specifically, this player-environment-centred approach to coaching underlines how, via the manipulation of task constraints, players can acquire and develop an in-depth understanding of functional tactical play configurations[2] (Renshaw et al., 2016).

Because of its ecological and dynamic nature, and due to it considers the bi-directional interactions between *player-player* and *player-environment*, concepts from the CLA have been used to explore how functional and coordinative structures (i.e., synergies) emerge, persist and change in team sports as a function of constraints interactions at a the micro-, meso-, and macro-levels of analysis (Ribeiro et al., 2020; Silva et al., 2016). Team synergy, a concept heavily scrutinised by Araújo e Davids (2016), refers to the ongoing coupling of the relatively independent degrees of freedom (*dofs*, e.g., players) within a dynamic system (e.g., a team). Such coupling is predicted by the attunement to surrounding information and the sharing of affordances *for* and *of* others among players, which enables the tactical synchronisation tendencies of team's sub-units (e.g., defensive or attacking phases of play) (Silva et al., 2013; Turvey, 2007). Accordingly, the synergy formation process is shaped by players' self-regulation and self-organisation abilities which, in turn, are supported by the cooperative role of players instead of their structural function (Araújo & Davids, 2016).

Overall, team synergy include four key properties: (i) dimensional compression, a process of coupling independent *dofs* so that synergies can

[2] The schema drawn from the relative spatial location of players according to the specific instructions received during training sessions (Gréhaigne & Godbout, 2014).

reduce their dimensionality (i.e., have less *dofs* than the set component from which it arises) (Riley et al., 2011); (ii) reciprocal compensation, which postulates that if an element (e.g., player) fails in its function, other elements (e.g., teammates) should adjust their roles so that the task goals can still be reached (Duarte et al., 2013); (iii) interpersonal linkage, corresponding to the specific contribution of each element to a group task (Eccles, 2010); and, (iv) system degeneracy, which describes how structurally different system components can perform similar, but not identical, functions according to the context requirements (i.e., ability to self-organise) (Edelman & Gally, 2001; Seifert et al., 2016). According to Ramos et al. (2020), most of the empirical analyses of team synergetic properties to date have focused on invasive team sports. Specifically, while the property of dimensional compression has been frequently investigated, in contrast the property of reciprocal compensation has been far less emphasised in the literature. In the case of non-invasive sports, there is a particular lack of investigations dedicated to understanding how teams lower their dimensionality, and how teammates adapt their roles so that the integrity of the team can be ensured and so that game goals can still be achieved. In fact, under rule restrictions, teammates in non-invasive team sports must cooperate efficiently and functionally to take advantage over their opponents in terms of time and space.

Particularly in volleyball, in reason of its non-invasive nature, as well as its various constraints imposed by the game-rules (namely, the limited number of ball contacts, the inability to grab the ball, the delimitation of offensive and defensive playing areas, and the player-rotation) it is crucial that players develop the ability to be perceptually attuned to relevant affordances so that they can exchange meaningful information with teammates and, consequently, maintain functional and structural integrity. This ability to be tactically aware of action opportunities (i.e., affordances) is of greatest importance during the counterattack-phase (or complex-II), which comprises the block, dig, set and attack actions (Martín & Santandreu, 2009). Specifically, complex-II can be divided into defensive- (i.e., block and dig actions) and offensive-subphases (i.e., set and attack actions), and these can start from two different game-scenarios:

(i) the service action, or (ii) the opponent's attack action (Mesquita et al., 2013). In both scenarios the ball possession belongs to the opposition team, and it is for this reason that during the counterattack-phase it is essential that players are able to identify and interpret the most relevant environmental constraints in order to cooperate functionally, co-adapt, and consequently take tactical advantage over opponents, thus overcoming the unpredictability inherent in competition.

In this respect, the set has been identified as one of the most vital competitive environmental constraints in volleyball (Marcelino et al., 2009). Considered as a "micro-game" within a game (Marcelino et al., 2012), the effects of different set moments (i.e., initial and final) on collective sport performance has been investigated within scope of volleyball performance analysis (e.g., Ramos et al., 2017). Another major competitive constraint identified in the current volleyball literature, is the opposition attacking context (i.e., playing *in*-system or *out*-system[3]). Frequently defined as setting options/conditions or number of hitters available, many studies have investigated how this competitive indicator can affect the performance of volleyball teams (e.g., Afonso et al., 2012; Ramos et al., 2017b). Although these past studies have been influential, research has yet to explore how initial and/or final set moments, as well as *in*-system and *out*-system opposition attacking context, might influence team synchronisation tendencies (i.e., synergetic property of reciprocal compensation) during competitive performances in volleyball. Moreover, no studies have sought to understand how the progressive increase and development of tactical complexity (i.e., playing with advanced tactical configurations of play, such as the double-block strategy) during training sessions might shape team synergy formation in volleyball competition.

Although the CLA has been dominant in presenting a theoretical rational for adopting training session designs focused on developing functional synergies, as well as identifying critical performance constraints, this ecological approach has not considered the nature, tactical specificities or didactical content of specific sports. Grounded on constructivist premises, the Step-Game Approach (SGA) is

[3] Playing in-system implies that all hitters are available, while playing out-system implies that only the outside-hitters and/or opposite are available (adapted from Laporta et al. (2018)).

a player-centred approach didactically conceived according to the specific nature of non-invasive team sports, like volleyball (Mesquita et al., 2005). This second-generation model (Ennis, 2014) is based conceptually on the tenets of the Teaching Games for Understanding (TGfU), with an emphasis on the comprehension of the logic and tactical structure of play before the teaching and practice of highly structured techniques (Bunker & Thorpe, 1982). From a didactical point of view, the SGA is grounded on the Skill Development Approach (Rink et al., 1996), which gives preference to different practice tasks (i.e., acquisition[4], structuring[5] and adaptation[6]) according to each stage of players' learning (Mesquita et al., 2005). Specifically, from the first to the last practice tasks, the variability of practice is gradually increased to accurately resemble game conditions (Pereira et al., 2011). In this sense, the time dedicated to the acquisition of tasks is reduced to the minimum required to avoid game disruption. Within SGA ideals, the specific development of performance abilities is accomplished by confronting players with step-by-step tactical problems during training sessions, which enables them to functionally form meaningful couplings between tactical behaviours and technical skills (Mesquita et al., 2005).

Given the aforementioned information, it is noted that CLA and SGA derive from distinct paradigms (i.e., ecological dynamics and constructivism, respectively) and thus have conceptual differences. Nevertheless, these approaches also share common theoretical points that, when combined in an applied and practical perspective, could lead sport practitioners (i.e., researchers, teachers, coaches, etc.) towards novel and useful insights about the interpretation of learning and sport performance (Renshaw et al., 2016). Specifically, the combined and long-extended application of SGA-CLA could extend our knowledge about how the pedagogical *process* underlying the design of representative and meaningful learning practice scenarios, through the manipulation of didactical augmented informational constraints, could impact on the competitive performance of the team.

[4] Focused on the development of a specific skill
[5] Focused on understand the tactical and technical skills of the game, but without opposition
[6] The goal, action structure, and basic tactical features are identical to the full version of the volleyball game

Explicitly, this pedagogical *process-oriented approach* encompasses coaches' pedagogical interventions dedicated to the design of learning tasks, during training sessions, in which action opportunities represent the competitive performer-environment interactions and are aligned with players' and teams' needs. As such, the pedagogical *processes* refer to *why* and *how* a set of task constraints are manipulated during practice so that players can improve their technical, tactical, physical and emotional domains during subsequent official matches. In doing so, the committed interplay among training and competition can be ensured, as stated at the beginning of this rational. Despite the potential relevance of this conceptual and practical integration, at present the constraint-led and step-game approaches have been analysed separately. Truthfully, and going deep into a pragmatic vision, these paradigms have been allocated at diametrically opposed, and therefore contradictory, positions. Nonetheless, according to Rink (2001), when we dedicate our efforts to prove that one paradigm is better than other, we limit our understanding about the complexity inherent to the teaching-learning process, as well as sport performance enhancements.

From an empirical research viewpoint, the CLA has been used to investigate the sports training context, and specifically how the manipulation of task constraints (e.g., number of players and playing field dimensions) shape the development of technical, tactical and/or physical performance of male footballers (Ometto et al., 2018). Also, while studies have explored how the manipulation of task constraints can influence the emergence of collective synergetic properties during training sessions, few studies have examined the synergetic property of reciprocal compensation, frequently expressed by team synchronisation tendencies, within competitive environments (Ramos et al., 2020). In fact, most of these studies performed cross-sectional and experimental designs to assess different training protocols (e.g., Coutinho et al., 2020), thus falling into a reductionist, cause-effect, and end-product perspective of sport performance development. Additionally, these investigations were typically conducted over brief periods within the training sessions (e.g., the first or last 20-minutes of practice) meaning they neglected the training process and disregarded the ecology and representativeness of the whole practice session (e.g., Oppici et al., 2018).

Furthermore, although CLA posits that coaches act *'sport ecology designers'*, prior studies that manipulated task constraints mostly avoided the coach intervention during its practical application (e.g., Travassos et al., 2018). By doing so, these studies neglected to consider one of the key pedagogical components responsible for evolving players' sport performance, which may contribute to false speculation of the empirical findings. The SGA, on the other hand, has gained prominence in the literature and has frequently been combined, due to its didactical emphasis, with other pedagogical models such as Sport Education (e.g., Araújo et al., 2017). However, the practical application of the SGA has been limited exclusively to the context of Physical Education (PE), meaning its potential benefits for developing players' sport performances during training and competitive environments remains unclear.

Accordingly, because studies focused on CLA and SGA have mostly been conducted within training or PE contexts, their potential impact on competitive performance has been undervalued. The analysis of performance throughout competitive environments is crucial given that competitive scenarios entail specific characteristics and represent reliable and legitimate sources of information to investigate sport performance (Eccles et al., 2009; Woods et al., 2019). In volleyball, the analysis of competitive performance has traditionally been accomplished using notational procedures (Mesquita et al., 2013), in which game sequences are recorded and analysed to inform about the 'what-who-where-when' of action execution (Hughes & Franks, 2004). Such studies usually rely on measuring unidimensional and discrete performance indicators (e.g., frequency and/or efficacy of actions) to accomplish correlational procedures so that future performances can be predicted (Glazier, 2010). By recording these types of performance indicators (i.e., outcome indicators), the interactions among players and the environment are disregarded, with the *why* and *how* of sport performance remaining unclear (Vilar et al., 2012). Moreover, by measuring uncontextualized numbers the didactical and procedural variables of performance (i.e., process indicators) have also been continuously neglected.

While it commonly accepted that the processes underlying improvement in learning, game-related knowledge, and competitive sports performance are important, the vast majority of the studies conducted so far have followed positivistic paradigms (Park et al., 2020). Typically, these investigations implemented methodological designs based on deductive methods that merely seek to generalise performance outcomes (i.e., an *end-product* perspective) (Mill, 1843). To update and integrate the link between product and process indicators of performance it is vital that the content of training sessions, namely the didactical design and specific goals defined for each learning task, is regularly and intentionally adapted according to competitive demands (e.g., opponent features) players' technical-tactical needs, and with indicators evaluated throughout the match (e.g., team synchronisation tendencies, set moment). The implementation of an Action-Research (AR) design is likely to be extremely helpful in this respect (Carr & Kemmis, 1986).

Due to its cyclical, reflexive, collaborative and interventionist nature, the AR-design offers the opportunity for sports practitioners (e.g., coaches) to continuously monitor, assess, adapt and reflect about his/her own practice, and thus intentionally change it as a results of their own reflections (Bodner & MacIsaac, 1995). Particularly, insider AR-designs (i.e. when the researcher assumes the dual role of coach-researcher) provide a unique and close view of the pedagogical coaching-learning process, allowing the coach-researcher to deliberately adapt the training plans as a function of the current needs of players and/or team (Coghlan, 2007; Farias et al., 2015). Indeed, built upon interpretative tenets (Carr et al., 1994), in which inductive reasoning (i.e., making broad generalisations from specific observations (Klauer, 1992)) is preferred, the AR-design offers the potential to extend current understanding about particular phenomena. In practical terms, the implementation of an AR-design, when ecological (CLA) and constructivist (SGA) approaches are combined, may be extremely useful for progressing current knowledge of how the pedagogical coaching process influences the development of players' game-related knowledge, the perceptual attunement of meaningful action opportunities, as well as the collective synchronisation tendencies.

Developing knowledge in this area of work (i.e., sport pedagogy, didactics, and performance analysis) is not just of theoretical value in sport science, but also crucial for enabling coaches to design effective and representative practice in team sports. Indeed, by adopting this integrative perspective it will be possible to champion the long-term development of holistic sport performance in youth players, rather than the short-term and superficial search for performance achievements.

1.2 Research problems and aims

To step further into a full and extended comprehension about the development of sport performance in youth volleyball players, the interplay of information between training and competition must be ensured. To this end, it is vital that the training approaches adopted do not only consider the ecology of the learning context, namely players-environment-task interaction (CLA), but also didactical content specific to each sport (SGA). Moreover, to monitor how the training process is effectively shaping competitive performance, it is necessary (i) a continual and close monitoring of the pedagogical coaching-learning process (based on AR-design), and (ii) that the performance indicators assessed in competition continue to be linked to the representativeness of practice so that the ecology between competitive performance preparation (training *process*) and performance in competition (*product* perspective) can be ensured. The accomplishment of these issues requires the exploration of several research questions that, to date, remain unclear in the literature. First, even though the importance of constructivist and ecological paradigms is recognised, there were not found studies exploring the potential of combining ecological representative designs (CLA) with a constructivist and sport-specific didactical approach (SGA).

Secondly, studies that analysed the pedagogical *processes* underlying the attainment of superior sport performances are also rare in the literature. Indeed, the research designs typically adopted, namely cross-sectional and experimental designs, only allow for the measurement of performance outcomes (*product* perspective). Accordingly, there is a clear gap in the literature regarding the application of interpretative paradigms and AR-designs throughout a full competitive sport season (i.e., adopting a longitudinal analysis).

Thirdly, few studies have been dedicated to the analysis of *player-player* and *player-environment* interactions during competition and how these interactions could be valuable indicators for guiding and optimising the design of didactical and representative learning tasks. In the specific case of non-invasive team sports, even fewer studies have examined how players and teams functionally co-adapt (i.e., synergy formation) in competitive environments. Indeed, in the case of volleyball there were not found studies that have analysed, over extended time-periods, the development of collective synchronisation tendencies (i.e., synergetic property of reciprocal compensation) in competition. Furthermore, there do not appear to be any studies that examined how increasing tactical complexity (i.e., evolving the tactical configurations of play) in training sessions influences the emergence of functional synergies in competition, enhanced according to the tactical sport specificities. In this respect, the interplay between players and the environment within a didactical and meaningful learning context supports the need of combine different, but complementary, approaches (CLA-SGA). Despite the relevance of considering the specificity of information provided to players during the practice, this issue has been also overlooked in the literature.

Finally, different set moments (e.g. initial and final) can influence subsequent volleyball actions, and there is a dearth of research investigating how team synchronisation tendencies evolve as function of this environmental constraint. Moreover, it remains unclear in the literature how the opposition attacking context (i.e., playing *in*-system and/or *out*-system) might shape the (re)emergence of functional synergies during the counterattack-phase.

Using an insider AR-design implemented across a competitive volleyball season, the general purpose of the present thesis was to examine the influence of combining ecological (CLA) and constructivist (SGA) approaches on the development of sport performance in female youth players. Specifically, it was aimed to:

- outline why an interplay between competitive and performance preparation data can widely contribute to improving the development of sport performance and to propose, from a methodological perspective, how it can be implemented and monitored so that the pedagogical processes inherent to sport performance development can be explored in-depth.
- search and examine how the manipulation of constraints (player, task, and environment) have shaped synergy formation, particularly the synergetic properties of dimensional compression and reciprocal compensation.
- quantify and compare findings related to the key synergetic properties of dimensional compression and reciprocal compensation within team sports performance.
- explore whether the SGA-CLA combination might serve as a useful framework for understanding how to enhance the development of players' tactical knowledge.
- analyse how increased tactical complexity in the counterattack-phase and subphases (i.e., offensive and defensive) might impact on teams' lateral and longitudinal synchronisation tendencies during competitive performance.
- investigate how different set moments (i.e., initial and final), and opposition attacking contexts (i.e., playing *in*-system and/or *out*-system) influence lateral and longitudinal team's synchronisation tendencies in competition.

1.3 The Role and Position of the Coach-Researcher

The present thesis can be considered innovative given its nature and chosen methodology. By implementing an insider AR-design, in which the researcher acted simultaneously as a head-coach, the thesis is able to highlight analyses pertaining to the coaching-learning process inherent in the development of youth players' sport performance. Given the main theoretical and practical assumptions of this research project, as well as my own academic background, my overarching aim was to develop a rich and meaningful understanding of this pedagogical *process*. Specifically, by shaping the learning environments (via constraints manipulation) according to the didactical content of volleyball on a daily basis, my focus was placed on developing players' sport performance in a holistic manner. Particularly, my approach was largely based on (i) what the current technical-tactical-emotional needs of players were, and (ii) how players could actively construct their knowledge so that they could respond to the training and competitive demands. Following this rationale, game-related knowledge and the players' cognitive engagement were viewed as the locus (i.e., the core) of a rich sport development from a long-term perspective. However, by also acknowledging the importance of learning environments and the acquisition of specific motor skills (i.e., technical-tactical abilities for playing volleyball), the representative and specificity principles of practice were equally highlighted and applied. Hence, my coaching philosophy embraced two well-known paradigms: ecologic dynamics and constructivism.

Accordingly, blending the aforementioned theoretical assumptions with the practical implementation of constructivist strategies (e.g., questioning, game-plan co-construction), as well as designing representative learning tasks, it was always very clear for me that, as a Researcher, my intentions were to acquire a close and deep engagement with players so that experiential learning could occur naturally. Thus, the final score of each official match was not seen as a vital target for me, but rather a consequence of a long and challenging journey. In doing so, I assumed that the development of players' sport performance was preferred over competitive achievements (e.g., final match-score, final team's ranking).

1.4 Thesis structure

This thesis was written according to the writing and presentation guidelines for dissertations of the Faculty of Sport University of Porto (FADEUP, 2009). Specifically, it uses the configurations of the Scandinavia model. The main reasons for choosing this model were familiarity, the ability to develop specific competences related to this knowledge domain, and the opportunity to produce scientific research. Indeed, the process inherent in scientific publication – comprising writing, submission, peer-review and finally publication – facilitates the development of critical thinking and sharing of distinct points of views that largely contribute to enhancing the quality of the research. Therefore, this thesis is formed of a set of chapters and scientific manuscripts that each address the overall objectives of the project. In this format it is possible to guarantee that the presented work meets the conditions and requirements of publication in international peer-reviewed journals with impact factor indexed. In summary, this thesis comprises one critical research note, one systematic review with meta-analysis, and three empirical investigations (please, see Table 1 for further details).

Chapter I presents the introduction to the thesis and provides the theoretical framework that supports the scientific investigations conducted. Here the relevance and novel aspects of this project are justified considering research currently published in the scientific literature. This chapter also outlines the general and specific objectives of the project followed, lastly, by a description of the thesis structure.

Chapter II, formed of one critical research note (submitted) and one systematic review with meta-analysis (published), integrates the theoretical components of the thesis. The critical research note, titled “How pedagogical process-oriented approaches capture the committed interplay between training and competition – A challenge for research designs”, presents a critical overview about why and how an interplay of information between training and competition, interlacing process-product perspectives, can improve the analysis and interpretation of sports performance. Specifically, this article proposes alternative methodological designs for redirecting the focus of research to the ongoing monitoring and assessment of the processes underlying the achievement of better sport performances. Hence, the current need to move from positivistic to interpretative paradigms supported the innovative methodological design adopted in the subsequent empirical articles. The review article is titled “The Constraint-led approach to enhancing team synergies in sport - What do we currently know and how can we move forward? A systematic review and meta-analyses”. This qualitative and quantitative review article provides a summary about the extensive body of work published on CLA and key synergetic properties (namely, dimensional compression and reciprocal compensation). Specifically, this article offers a synthesis of information about the designs, contexts, samples, sports, variables evaluated, type of constraints manipulated, statistical methods and main findings of past scientific investigations. This study also offers suggestions for future research and discusses practical implications for sport practitioners. The conclusions from this review guided, in terms of theoretical framework, the research focus of the three following empirical articles included in this thesis.

Chapter III incorporates the empirical component of the thesis. Specifically, this chapter presents three empirical studies (one qualitative and two quantitative) that are either published or under review (at the time of thesis submission). The first empirical study is titled "Developing players' tactical knowledge using combined Constraints-led and Step-Game Approaches – A longitudinal action-research study". This qualitative investigation examined, using an insider AR-design, the impact of combining concepts of two contemporary approaches (CLA and SGA) on the development of youth volleyballers' tactical knowledge. Specifically, this article sought to demonstrate the potential of combining CLA and SGA to (i) enhance the perceptions and actions of developing athletes, (ii) address the complexity of practice demands and the individual needs of players and teams, and (iii) offer a deep, interpretative and contextualised analysis of the coaching process. The second empirical study has the title "Increasing tactical complexity to enhance the synchronisation of collective behaviours: An action-research study throughout a competitive volleyball season". This quantitative study examined the influence of increased tactical complexity on team synchronisation tendencies during the counterattack-phase. Specifically, the study analysed, from a macroscopic perspective (i) how the synergetic property of reciprocal compensation evolved over the season, (ii) how a coaching intervention (i.e., the design of didactical and representative practice sessions) influenced the process of synergy formation, and (iii) how competitive environmental constraints (i.e., initial and final set moments) influenced collective synchronisation tendencies. The third empirical study was titled "How can team synchronisation tendencies be developed combining Constraint-led and Step-

Game approaches? An action-research study implemented over a competitive volleyball season". This quantitative study explored the impact of increased tactical complexity on team synchronisation tendencies in competition via a meso-scale level of analysis; that is, during defensive (no ball-possession) and offensive (ball-possession) counterattack-subphases. Particularly, this study investigated; (i) how synchronisation tendencies at each counterattack-subphase progressed over the season, (ii) the role that a coaching intervention (i.e., the manipulation of sport-didactical and informational constraints) played on the process of synergy formation in competition, and (iii) how the opposition attacking context (i.e., playing *in*-system and/or *out*-system) influenced collective synchronisation tendencies.

Chapter IV is dedicated to the general discussion and the concluding remarks. The discussion within this chapter is framed upon the theoretical assumptions investigated and supported by the main findings of each empirical article. Specifically, the results of each study are combined, interpreted and discussed in an attempt to (i) extend current knowledge of the pedagogical processes underlying the holistic and long-term development of sport performance in youth volleyball players, and (ii) understand the advances, setbacks, and the strategies used to overcome the problems faced throughout the competitive season. Finally, practical implications for coaches are considered, future avenues for scientific research are recommended, and limitations of the current thesis are acknowledged.

The supplements section includes two similar tables, each one submitted as supplements during the submission of the second and third empirical studies, respectively. The references of each chapter are presented at the end of each respective chapter. In addition, the references of each study are presented at the end of the manuscript according to the publication guidelines of the journal in which each study was published or submitted. Table 1 provides a summary of the structure, contents, and studies included in this dissertation.

Table 1. Synopsis of the structure, contents and studies included in the present dissertation

Chapter I	Introduction
	Theoretical framework, pertinence of the investigation, research questions and purposes as well as the structure of the dissertation
Chapter II	Theoretical Articles
Critical Research Note	**How pedagogical process-oriented approaches capture the committed interplay between training and competition – A challenge for research designs** *Ramos, A., Coutinho, P., Davids, K., & Mesquita, I.* Submitted: Physical Education & Sport Pedagogy (IF: 2.618)
Review Article	**The Constraint-led approach to enhancing team synergies in sport - What do we currently know and how can we move forward? A systematic review and meta-analyses** *Ramos, A., Coutinho, P., Leitão, J., Cortinhas, A., Davids, K., & Mesquita, I.* Accepted: Psychology of Sport & Exercise (IF: 2.827) DOI: 10.1016/j.psychsport.2020.101754
Chapter III	Empirical Articles
Empirical Study 1	**Developing players' tactical knowledge using combined Constraints-led and Step-Game Approaches – A longitudinal action-research study.** *Ramos, A., Coutinho, P., Davids, K., & Mesquita, I.* Accepted: Research Quarterly for Exercise and Sport (IF: 1.883) DOI: 10.1080/02701367.2020.1755007
Empirical Study 2	**Increasing tactical complexity to enhance the synchronisation of collective behaviours: An action-research study throughout a competitive volleyball season** *Ramos, A., Coutinho, P., Ribeiro, J., Fernandes, O., Davids, K., & Mesquita, I.* Accepted: Journal of Sports Sciences (IF: 2.597) DOI: 10.1080/02640414.2020.1794265
Empirical Study 3	**How can team synchronisation tendencies be developed combining Constraint-led and Step-Game approaches? An action-research study implemented over a competitive volleyball season** *Ramos, A., Coutinho, P., Ribeiro, J., Fernandes, O., Davids, K., & Mesquita, I.* Accepted: European Journal of Sport Science (IF:2.781) DOI: 10.1080/17461391.2020.1867649
Chapter IV	Concluding Remarks
	General discussion, practical applications, suggestions for future studies, and synopsis of the main findings.

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Chapter II: Theoretical Articles

Critical Research Note

How pedagogical process-oriented approaches capture the committed interplay between training and competition – A challenge for research designs

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Abstract

Background: Despite the long-established premise that competitive performance data should inform performance preparation (training designs), researchers have tended to investigate athlete performance behaviours in competition and practice separately. Furthermore, analyses of training or competition environments, typically used in research designs, tend to record performance execution – adopting a product-oriented perspective – commonly ignoring the pedagogical and didactical processes underpinning functional achievement of performance goals (i.e., the how and why of performance evolution). Thus, to move forward within the sport pedagogy and athlete sport performance development a different perspective is currently needed. However, this radical transition may require a change in applied research designs and scientific paradigms adopted.

Purpose: The aim of this paper is to outline the relevance, and current need for, integrating information of performance between competitive and training environments, suggesting alternative and sophisticated methodological designs for future research studies to monitor, explore, and describe in-depth the pedagogical processes of sport performance and their development.

Design: Based on data from illustrated studies within the scope of sport performance analysis and athlete performance development we demonstrate, in a critical fashion, how sport performance has been investigated. In doing so, we emphasise the current need of include the interpretative paradigm and the coach experiential knowledge so that the pedagogical processes inherent to the achievement of superior performance can be comprehended.

Findings: Summarising the findings, we highlight that an interpretative paradigm, combined with non-linear metrics that spotlights the dynamical athlete-environment interactions in competition and practice, could be extremely useful to examine and understand in-depth the pedagogical processes underlying athletes and teams development. In addition, we emphasise how the continuous integrative exchange of performance data between competition and training can be mediated by coaches' experiential knowledge. Finally, we underline that redirecting the practice focus from performance products (i.e., performance outcomes – broad statistical patterns and generalisations) to pedagogical processes (i.e., performance development – in-depth analysis of a performance phenomenon), may redress current misalignment between theory and practice. In this sense, sport science research may elaborate research questions attuned to actual pedagogical challenges, by explaining empirical findings with experiential and contextualized lenses.

Conclusion: The experiential knowledge of coaches and practitioners can mediate the continuous information exchange needed between training and competition, supporting the emergence of a new interactive knowledge triangulation: competition-coach-training. This triad needs to be better acknowledged in future research investigations. Also, by adopting sophisticated research designs aligned with coaches and athletes' needs, it will be possible to bridge the gap between theory and practice, and concomitantly enriching the understandings about the pedagogical processes underlying sport performance development.

Keywords: Sport Pedagogy, Process-oriented Approach; Coach Experiential Knowledge; Research Design; Athlete Performance Development

Introduction

In developing a better understanding of sport performance, researchers typically seek a strong correspondence of information between training and competitive environments. For example, in motor learning, a key issue concerns the implementation of the longstanding principle of training specificity, related to the importance of designing practice tasks representative of competition (Henry 1958; Proteau 1992). Associated with practice specificity, the ecological concept of representative design has gained a prominent emphasis in protocols for competitive performance preparation (Travassos et al. 2012), by reinforcing the need to design learning tasks that include the same informational constraints of competitive environments (Pinder et al. 2011), challenging coaches to sample the most relevant information from competition (Woods, McKeown, Rothwell, et al. 2020). Frequently guided by their experiential knowledge, coaches retrieve and interpret competitive data, distilling it into practice designs which guide athletes to perceive and utilise relevant affordances ('action opportunities'(Gibson 1979)) (Greenwood, Davids, and Renshaw 2013). Therefore, a major task for applied sport scientists is to develop evidence-based methodological designs which enhance our understanding of the pedagogical processes underlying the practical interplay between training and competition data.

Here, we conceptualise a process-oriented approach encompassing pedagogical interventions dedicated to the design of practice programmes in which action opportunities represent competitive performer-environment interactions and are better aligned with athletes' needs within competition. Explicitly, pedagogical processes refer to the why and how a set of task constraints are manipulated during practice by sport practitioners for emergence of technical, tactical, physical and/or emotional competitive performance outcomes. For instance, in a volleyball training application, if the match-report (i.e., data on individual and collective frequencies and efficacy of actions – product perspective) portrays low values of blocking percentages, subsequent training sessions could address this issue in diverse ways. Here, the richness in analysing the pedagogical performance development process could encompass an in-depth examination about, not only why sport practitioners could use the statistical data retrieved from competition, but also indicating how – didactic viewpoint – to design relevant practice tasks, congruent with specific competitive demands and teams preparatory needs. Several limitations are currently inhibiting progress of this pedagogical process-oriented approach to applied sport science research which we evaluate here.

First, despite the need for clear association between training and competition data, applied scientists have tended to investigate them independently (Taylor et al. 2020; Coutinho et al. 2020). This de-compartmentalisation on investigating training and competitive performance contraries the well-known assumption that athletes rely on to enhance competitive performance, and behind coaches use data from competitive performance to improve training designs and satisfy athlete needs. This separation provides a lack of clarity on how each context mutually influences the other (i.e., is the way a team trains closely aligned with how it competes? Are competitive constraints faithfully represented in training tasks?).

Second, constraints on competitive performance have increasingly been analysed using analytical methods (Glazier 2010). By providing decontextualized data and statistical patterns (e.g., actions frequency in a ‘what-where-when-who’ sequence of analysis), a data-driven approach runs the risk of falling into a reductionist, and linear, cause-effect vision of competitive performance that disregards the emergent nature of continuous performer-environment interactions (Vilar et al. 2012; Ribeiro et al. 2019). Because team sports are viewed as complex and dynamical system, the emergent interactions between players represents a core concept that must be considered in performance analysis (Balagué et al. 2013; Duarte, Araújo, Correia, et al. 2012). Indeed, due to inherent self-organisation tendencies, players’ interactions continuously arise, switching the team organisational state so that it can rapidly co-adapt to dynamics of the environment and achieve intended performance goals. These collective system properties are challenging to measure using traditional analytic methods. Thus, an ecological dynamics framework has been endorsed to evaluate how performer-environment nonlinear interactions continuously emerge to shape sport performance (Davids et al. 2015; Woods, McKeown, Rothwell, et al. 2020).

Third, many investigations adopting an ecological paradigm have been conducted in training contexts, using cross-sectional designs framed upon positivist research premises, in which interventionist protocols are implemented over short-periods of practice (e.g., first or last 20-minutes) (Oppici et al. 2018). These research investigations have successfully informed academics and coaches about the performance outcomes (e.g.., comparing tactical capacities and skills of athletes before and after a planned intervention). To move forward, however, researchers need to explain and interpret the effects of ecological assumptions on athletic performance, considering the training process as a whole (e.g., contemplating the global training structure, and re-designed learning tasks throughout extended timescales).

Fourth, many interventionist studies, while adopting innovative approaches, explicitly require in their research designs that coaches do not provide any feedback to athletes(Travassos et al. 2018). This is unrepresentative of pedagogical behaviours in practice contexts since the coach's role is reduced to a mere planner of training tasks. This reductionist pedagogical position has been broadly criticised because coaches are not allowed to be actively engaged in athlete performance development (Roberts, Newcombe, and Davids 2019). For example, Ribeiro et al. (2020) showed how pedagogical principles of ecological dynamics asserts that a subtle balance is continuously needed in providing both local (interpersonal athlete interactions) and global (coach guidance to athletes) directional influences on athlete and team interactions within practice learning designs.

Overall, these critical issues illustrate how some competition-training informational linkages in pedagogical practice may be currently dysfunctional, giving rise to the following overarching questions: (i) Has sport science research focused enough on the relevance of how coaches use competitive data to underpin practice and performance processes during long-term training programmes? This mutual interaction among product-process oriented data could favour an interpretative analysis about how performance can be developed over time – pedagogical and didactical view –, rather than focusing on what performance outcomes can be reached; (ii) Have prevalent sport science research designs been appropriately aligned with understanding of how athletes prepare to compete? (iii) What role does a coach's experiential knowledge (CEK) have in leading pedagogical processes inherent to competitive performance preparation and athlete development? (iv) Can the CEK support the complementary relations developed between theory and practice within an applied sport science context? To respond to these key issues, it is necessary to redirect the research focus to understanding performance achievements as final products of a continuous and dynamic pedagogical process. In other words, sport science research needs to focus on interpreting performance outcomes by examining the cyclic pedagogical and interventive process of how competitive preparation is planned, implemented, and intentionally changed to face subsequent competitive demands. Specifically, it is worth examining why, and how, coaches design their training sessions and what the implications of these design processes are for athlete competitive performance.

In this paper, we seek to highlight the importance of considering the nuanced interplay of information between competitive and performance preparation data, and to propose, from a methodological viewpoint, how it can be re-established and refined in future investigations. In this sense, we start by scrutinising how competitive performance data can guide coaching and athlete preparation for performance development and competitive performance. Next, we propose alternative methodological research designs so that future applied scientific studies can monitor, explore, and examine in-depth the pedagogical processes underpinning sport performance development. Finally, we discuss the role of CEK and sport practitioners in bridging practice and theory for the purposes of enhancing sport performance.

How can the analysis of competitive data support the pedagogical coaching practice? An interplay disregarded by the dark side of performance analysis

Using information from competition, coaches seek to develop most functionally relevant 'technical-tactical-psychological' athlete skills needed for successful performance in future competition, recognising that preparation for each challenge must be adapted considering particular opponent's strengths and weaknesses (Woods et al. 2019). Specifically, competitive performance analysis can inform pedagogical practice by: (i) providing feedback about the previous competitive performance, (ii) advising on critical events, features and/or tendencies that may arise during the next competition, (iii) affording feedback for the design of representative training sessions (Eccles, Ward, and Woodman 2009; McCosker, Renshaw, Greenwood, et al. 2019).

Supported by competitive data, practice programmes frequently has two main interventionist purposes: Coaching for Athlete Development (CAD, i.e., the focus is fully placed on the enhancement of athletes skills and expertise throughout their development) and Coaching for Competitive Performance (CCP, i.e., the focus in placed on achieving a successful performance outcome, such as winning a competition). The relationship between CAD and CCP is very clear and can be observed at different stages of performance (i.e., from novice to expert athlete) and scales of analysis as function of interacting personal (e.g., ageing), task and environmental (e.g., competition structure) constraints(Chow et al. 2020; Woods, McKeown, O'Sullivan, et al. 2020; McCosker, Renshaw, Russell, et al. 2019). From a macro-scale of analysis, and without ignoring CCP, at novice performance stages the focus is – or should be – placed on CAD, while at the expert performance level this relationship is reversed to place more emphasis on CCP area, preventing the treatment of youth athletes as 'mini-adults'. From a meso-perspective, when coaches are structuring their practice micro-cycle, the beginning of the week is commonly dedicated to CAD, and CCP becomes more prevalent as it gets closer to competition. At a micro-perspective, the training-unit design frequently encompasses CAD for initial and/or individualised learning tasks (e.g., integrating sub-units of the team), ending in CCP on collective and competitive tasks (e.g., full-game version constrained by game-rules).

Regarding the competitive data record, sport practitioners have used notational analysis for decades to structure training content for athletes and teams (McGarry 2009). However, by correlating action frequency with final outcomes (e.g., score or error) the dynamic athlete-environment interactions are disregarded (Duarte, Araújo, Folgado, et al. 2012). In an attempt to deal with this issue, the ecological dynamics framework, aided by nonlinear metrics, has sought to explain how such interactions restrict the emergence of different game patterns (Araújo, Silva, and Davids 2015). However, the application of nonlinear metrics uncovers dense information that is often difficult for coaches to interpret, challenging the design of representative learning tasks. The practical applications of these investigations are thereby often misunderstood, leading to a widening gap between theory (researchers) and practice (coaches) in what sport pedagogy regards.

By cross-sectionally analysing the impact of isolated experiments, the investigations have provided detailed and relevant information about how the constraints manipulation affect sport performance (Gonçalves et al. 2018b).

However, and concomitantly, such studies have also omitted in some cases, and annulled in others, the ecology and representativeness inherent to an effective competition-training interplay. Indeed, these empirical works rarely considered – or reported – why specific constraints were manipulated, what their relevance was for – and didactical alignment with – the team tactical needs. Accordingly, the representativeness of neither the task nor the training was ensured, resulting in a meaningless practice for athletes and decontextualized researches for coaches. This issue was recently highlighted by Fullagar et al. (2019), who argued that practitioners have lamented that research questions remain misaligned with coaches' needs, inhibiting the implementation of scientific evidence into practice. The representativeness of the entire practice session is therefore a major educational issue that must be considered once the learning and development of performance is athlete-dependent: it occurs when the athlete intends and is predisposed to it, and not when the coach desires (Ennis 2014).

Because of these methodological issues, the pedagogical process inherent to the development of athletes' holistic sport growth has been overshadowed by the dark side of sport performance, so far mainly in the form of generalised recipes that presuppose to guide athletes towards performance enhancements. The reversing of this trend requires firstly to retrieve accessible information from competition that considers the interactive nature and complex character of the competitive environment so that the design of training session can be as representative as possible; and secondly to examine the training process 'as a whole' in order to fully understand how practice is designed to bridge the athletes competitive needs. Afterwards, the (re)establishment of competition-training retroactive feedback requires a change from product to process perspectives, which is expressed by the adoption of an interpretative paradigm and inductive reasoning.

What can we do in future research investigations? – Redefining methodological routes

As previously stated, the sport performance analysis in training and competition has been following a positivistic paradigm. According to Gage (1963), paradigms are models, or modes of thinking/inquiring, that lead to the conceptualisation of theories. Positivism has tendencies for deductive reasoning that starts with a general statement and examines the possibilities of reaching specific and logical conclusions (Ennis 1969; Mill 1843). For example, applying Popper's falsification theory, a researcher can hypothesise that all swans are not white. Presuming that next the researcher spots a black swan in a particular place and at a specific time, he/she may logically deduce that all swans are not white, and that the truth of the hypothesis is overwhelming (Popper 1969). Thus, in deductive inference, one predicts – and claims to explain – what the observations should be if a theory were correct. The major concern is, therefore, the spread of generalisations (Park, Konge, and Artino 2020).

However, it is worth highlighting that sport is a largely social phenomenon, thereby the paradigm adopted for its analysis must be aligned with its human nature (Giulianotti 2016). Thus, it is also necessary to consider the well-established interpretative paradigm (Carr et al. 1994). Usually related with social and human sciences, this paradigm advocates an inductive reasoning that makes broad generalisations from specific observations (Klauer 1992). Specifically, many events are observed, patterns discerned, and explanations inferred. The main advantage of the interpretative paradigm is its focus on trying to understand in-depth a phenomenon, such as the meaning of athletes' behaviours within a specific context (Light and Wallian 2008). In this paper we advocate that to comprehend the pedagogical process (inductive reasoning) instead of seeking to explain the sport performance products (deductive reasoning), it is essential to reformulate research designs. It seems pertinent to state, nonetheless, that in science there is an ongoing interchange between inductive and deductive inference until we get closer to the 'truth,' which we can only consider but not ascertain with complete assurance. Next, we propose several somewhat innovative ideas that could – and perhaps should – be included in the research designs of future investigations.

First, regarding data analysis from competitive performance, we suggest longitudinal investigations with ongoing tracking of 'dynamic match-analysis' (i.e., the performance indicators are selected and measured according to what was trained). As athletes train to compete, the information retrieved from competition must be aligned with what was intended to be developed. For that purpose, we endorse the integration of nonlinear metrics with linear and robust statistics (Ribeiro et al. 2020). Doing so ensures that the information collected is representative of the competition after considering the complexity of athletes-environment interactions, and not fragmented into cumulative statistical procedures that disregards its real ecology. Afterwards, the comparisons and/or inferences through linear procedures may facilitate the sharing and disclosure of information to coaches improve their pedagogical praxis.

Second, we recommend the implementation of Action-Research (AR) designs (Carr and Kemmis 1986), characteristic of the interpretative paradigm, and which have scarcely been applied to sports training context. Studies focused on understanding sport performance enhancements could benefit from this design given its cyclical and reflexive nature (Cooke and Wolfram Cox 2005; Ollis and Sproule 2007), and because AR affords the ability to monitor, assess and intentionally adapt coaching interventions designed to achieve superior performance over extended time-periods. Also, aligned with interpretative approaches, the adoption of qualitative research designs could unearth unique information (‘why’ – pedagogy and how - didactics) for sport practitioners to possess about performance development (Ramos, Coutinho, Davids, et al. 2020; Gubacs-Collins 2007).

Third, and perhaps the most innovative idea, we suggest the integration of nonlinear metrics and linear statistics within an interpretative approach to extend the phenomena comprehension. For instance, Ramos, Coutinho, Ribeiro, et al. (2020) analysed the development of competitive sport performance (expressed by team synchronisation tendencies) over three AR-cycles implemented throughout a sport season. The authors used nonlinear metrics to collect information about how players ongoingly interact in competition, and traditional statistics to compare such interactions at different season periods. Thus, by adopting a collaborative and intentionally interventive approach, within a qualitative interpretation monitored over-time, it was possible to describe and comprehend the main events that dictated changes in the team's performance – pedagogical process-oriented approach.

Despite the methodological designs exemplified, these studies currently represent exceptions, and not a trend, within the field of sport performance research. Therefore, to the best of our knowledge, there is an urgent need to redirect research investigations toward pedagogic process analysis and, based on its interpretation, understand and explain the performance outcomes.
Within these research-designs, should the coach be part of the equation?

Coach's experiential knowledge: The secret ingredient disregarded by empirical research designs

Implicitly embedded in athlete development, coaches are undeniably orchestrators of performance (Jones and Wallace 2006; Jones and Turner 2006). Being responsible for the pedagogic process of preparing athletes to accomplish superior outcomes, coaches frequently analyse competitive data, interpreting it based on their experiential knowledge acquired over years of practice (Beek 2000). As such, the CEK must be more often considered as a crucial ingredient within the methodological designs proposed. Specifically, coaches should be viewed as bridges that mediate the information exchange between training and competition, once they convert, by acting as performance facilitators, the most relevant competitive data into representative and meaningful learning tasks for athletes (Woods, McKeown, Rothwell, et al. 2020). It is precisely in this sense that, grounded on CEK, the triangulation of performance information could be defined in a 'competition-coach-training' triad, which must be acknowledged in the research design of future investigations.

Despite the potential benefits that CEK could have as an additional source of information for academics, it has typically been neglected. Attempting to call out this issue, Greenwood, Davids, and Renshaw (2012) demonstrated how experiential knowledge could be a vital information source, suggesting that future studies must integrate it with empirical knowledge so that pedagogical and applied science could progress. Indeed, if we claim to integrate and explore deeply the complexity and ecology of sport performance, by disregarding the coach's role (e.g., avoiding the coach intervention during experiments) we are neglecting one of the most important parts of 'the whole', which limits our comprehension of phenomena. It is worthwhile to highlight, however, that we are not arguing that experiential knowledge can substitute empirical research. Rather, we agree with the assumption that it could be a complement to an empirical understanding of performance, and we go further by outlining that it might be a relevant concept to mediate the training-competition information exchange. Precisely for that reason, in future investigations the research designs must encompass a contemporary model that links CEK with empirical knowledge (Rothwell et al. 2020).

Conclusions and Practical Applications

In this paper, we demonstrated the importance, and current need, of practical and theoretically re-establish the interplaying information among training and competitive environments. Framed upon an interpretative paradigm, innovative research designs are suggested so that an in-depth comprehension, rather than broader generalisations, of sport phenomenon can be attained. Furthermore, we addressed that the ongoing exchange of performance data is mainly mediated by CEK, suggesting that an informational competition-coach-training triad should be considered in future studies. By adopting sophisticated research designs aligned with coaches and athletes' needs, we believe that we are bridging the gap between theory and practice, and concomitantly enriching the understandings about the pedagogical processes underlying sport performance development.

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Review Article

The Constraint-led approach to enhancing team synergies in sport - What do we currently know and how can we move forward? A systematic review and meta-analyses

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Abstract

Background: During the past decade, an extensive body of work has documented the Constraints-Led Approach (CLA) as a prominent methodology for developing collective synergetic tendencies in sports teams.

Objectives: This study aimed to quantify and compare findings, in existing research, related to key synergetic properties of dimensional compression and reciprocal compensation in team sports performance.

Method: A literature search was conducted for articles published until December 2019, on electronic databases PubMed, Scopus, EBSCO, SPORTDiscus, Web of Science, and Google Scholar. Inclusion criteria were defined before the selection process. From selected articles information was extracted on authors, year of publication, study design, study context, sample, sport, variables assessed, type of constraints manipulated, statistical methods, and main findings. The manuscripts' methodological quality was assessed through the Downs and Black checklist. A meta-analysis was performed using a random-effects model and subgroup analyses were conducted for two potential moderators: dimensional compression and reciprocal compensation.

Results: A total of 62 and 26 studies met the inclusion criteria for systematic and meta-analysis, respectively. Results revealed that investigations tended to mostly evaluate how task constraints manipulations shaped emergent tactical behaviors of male football players within training contexts. A high level of heterogeneity (I^2 = 99.56%, $p < .001$) was found across studies and publication biases were observed in the literature.

Conclusions: The high level of heterogeneity is possibly justified by the diversity of metrics applied to assess players' performance behaviors. The level of research heterogeneity observed also supports the assumption that variable behaviors enhance adaptive tendencies in teams. Observed publication and inflation biases highlighted the need to adopt methodological procedures that avoid systematic flaws in future investigations.

Keywords: constraints-led approach; synergy formation; quantitative review; team sports performance; practice learning designs; research methods

Introduction

Grounded in concepts of dynamical systems theory and ecological psychology, integrated in an ecological dynamics rationale (e.g., Chow, Davids, Button, Shuttleworth, & Araújo, 2007), the Constraint-led Approach (CLA) has investigated how athletes and teams coordinate and adapt their behaviours under interacting task, organism, and environmental constraints (Davids & Araújo, 2005; Renshaw, Chow, Davids, & Hammond, 2010). Constraints are conceptualized as boundaries that shape the emergence of behaviour (Newell, 1986), facilitating opportunities for individuals to interact with the environment (i.e., affordances (Gibson, 1979)). Based on the work of Renshaw and Chow (2019), the following constraints were considered: athlete (organismic) constraints (e.g., age and expertise level), environmental constraints (e.g., key moments of performance, the competitive performance environment per se, and match status), and task constraints (e.g., number of scoring targets used in training practices, numerical relations between players in SSCGs, small sided game formats, practice game rules, field dimensions, and relative co-positioning of players).

In the past decade, the CLA has been widely investigated as a prominent methodology for developing collective, functional synergetic tendencies in sports teams. In this performance context, tendencies for synergy formation between performers has been of particular interest to facilitate the design of practice tasks to support synergy formation between attacking and defending players during performance (e.g., Araújo & Davids, 2016; Ribeiro et al., 2019; Silva, Chung, et al., 2016) Most studies using a CLA have been focused on how the manipulation of different task constraints shapes athletes' goal-oriented behaviours (e.g., Gonçalves, Marcelino, Torres-Ronda, Torrents, & Sampaio, 2016; Menuchi, Moro, Ambrósio, Pariente, & Araújo, 2018). Furthermore, many studies have investigated how constraints manipulation in learning design may influence player and/or team synergetic behaviors (Olthof, Frencken, & Lemmink, 2017; Silva, Chung, et al., 2016; Travassos, Coutinho, Gonçalves, Pedroso, & Sampaio, 2018). Given the amount of information continuously emerging from research on team sports performance, adopting a CLA methodology, summaries of the main research findings are constantly needed to update our understanding of effects. To exemplify, Ometto et al. (2018) published a systematic review to investigate which task constraints have been most frequently manipulated when using small sided and conditioned games (SSCGs) (conceived as smaller versions of the formal game) during practice. Their qualitative review also reported the impact of such manipulations on emerging tactical behaviours, technical actions, and co-positioning between participants. Overall, they reported that investigators tended to manipulate only one or two constraints during training, most frequently involving changes in numerical relations between players (overloading or underloading) and playing area dimension values. Despite its relevance, the study by Ometto and colleagues (2018) only included investigations of SSCG designs in football training sessions. Therefore, pertinent questions concerning the application of CLA methodology in team-sports remain unanswered, such as: what type of participant samples have been largely examined? What study designs have been mainly utilised? Which study contexts (i.e., training, or competitive performance environments) have been preferred? Which synergetic properties have been most frequently analysed? These are precisely the questions that we intend to address in this quantitative review.

Collective behaviours in sports teams (i.e., team tactical behaviours) have been defined as emerging from synergy forming tendencies (i.e., a group of relatively independent degrees of freedom (e.g., players) can spontaneously co-regulate behaviours to temporarily function as a sub-unit (e.g., when attacking or defending), under constraints) (Araújo & Davids, 2016). An ecological dynamics rationale proposes that such collective behaviours emerge as a consequence of athletes' perceptual attunement to shared affordances (individuals learning to pick up and use co-perceived opportunities for action in the performance environment) (Silva, Garganta, Araújo, Davids, & Aguiar, 2013). According to Araújo and Davids (2016), team synergies comprise four properties: dimensional compression, reciprocal compensation, interpersonal linkage and system degeneracy. Previous analyses of team synergies have highlighted the significance of dimensional compression (i.e., a process of decreasing dimensionality which emerges through the increased coupling of hitherto independent degrees of freedom) and reciprocal compensation (i.e., adaptative behaviours of other athletes, when a teammate does not fulfil a function, in order to achieve a task goal) (Araújo & Davids, 2016; Beek & Daffertshofer, 2014; Latash, 2008). On the other hand, the study of interpersonal linkages (i.e., the specific contribution of each player to a group task) and system degeneracy (i.e., the ability of structurally different system components (e.g., players in a team) performing similar functions considering contextual specificities) has been less emphasized in the literature. However, to date, no systematic reviews with meta-analyses have investigated how the CLA methodology has been applied with respect to developing synergies in sports team. Specifically, a quantitative review is needed, in order to estimate the magnitude of statistical differences reported across emerging studies, to provide information about how constraints manipulations as a pedagogical approach in team sports training have impacted on the development of team synergetic tendencies.

Tendencies for dimensional compression and reciprocal compensation have been the synergetic properties most frequently investigated in the literature so far. Therefore, through a systematic review and meta-analysis, the purpose of the present study was to quantify and compare findings related to these key properties. Specifically, we aimed to examine how the methodology of constraints manipulation (athlete, task, and environment) shaped the dimensional compression and reciprocal compensation of synergies formed by players in SSCG performance. We expected to draw evidence-based conclusions that may guide future academic investigations and coaching practice.

Methods

This study was approved by the local Institutional Research Ethics Committee of the first author’s institution, and followed the guidelines stated in the Declaration of Helsinki.

<u>*Systematic Review Procedures*</u>

Eligibility criteria

After recommendations of Simmons, Nelson, and Simonsohn (2011), eligibility criteria and the type of variables under analysis were defined prior to the electronic search. In order to maintain quality assurance, and due to the possibility of the reported data having not been subjected to an independent, expert peer-review process, conference abstracts, chapters, dissertations and theses were excluded from analyses. For the same reason, articles published in non-peer-reviewed journals and/or those without an indexed impact factor were also omitted. Due to the specific purpose of this study, publications reporting investigations in physical education contexts were also excluded. Finally, pilot, case studies or studies that presented variables and/or concepts not related to a CLA methodology were excluded.

Peer-reviewed studies were included taking into account the following criteria: (i) the article had to focus on theoretical concepts from a constraint-led approach applied to the analysis of dimensional compression and/or reciprocal compensation properties within a training or competitive performance context (see Table 1); (ii) the articles had to be empirical and use quantitative research methods so that they could be integrated in the meta-analysis procedures; and (iii), the article had to be written in the English language with full-text available, and published in a journal with an indexed impact factor. In addition, no restrictions were placed on participants' age, skill, or sex. Finally, articles focused on both individual and team sports were included in the systematic review. However, due to unsuitable data formats, the meta-analyses only encompassed studies focused on team sports (i.e., activities in which team members established inter-dependent relationships at different sub-group levels with the intention of achieving common collective outcomes (Evans, Eys, & Bruner, 2012)).

Data sources and search strategy

A systematic review and meta-analysis were conducted in accordance with the recommendations outlined in the Preferred Reporting Items for

Systematic Reviews and Meta-Analyses (PRISMA) statement (Moher et al., 2015). An electronic literature search was undertaken for articles published up to, and including, December 2019 on the online databases PubMed, Scopus, EBSCO, SPORTDiscus, Web of Science, and Google Scholar. The search terms, the search strategy and the respective results by database are presented in Table 1. The reference lists of the selected articles were also screened for potentially suitable articles to include in the review.

Next, titles and abstracts of retrieved articles were individually evaluated by the research team to assess their eligibility for review and meta-analysis. The reviewers were not blinded to the list of authors, the institutions, or the journals of publication in the selected studies. Any disagreements on study selection were resolved consensually. The study abstracts that did not provide enough information according to the eligibility criteria stabilized were retrieved for full-text evaluation.

Table 1. Search terms and search strategy used in all databases with the respective amount of results found

Search terms	Database	Results/Papers
(1) constraint-led approach (2) "affordances" OR "task constraint" OR "constraints manipulation" OR "performance analysis" OR "synergies" OR "coordination" OR "tactical behaviour" OR "collective behaviour" OR "ecological approach" OR "ecological dynamics" OR "dynamical systems" OR "variability" OR "representative design" (3) "sport" OR "team" OR "player" **Search strategy:** (1) AND (2) AND (3)	PubMed	10
	Scopus	619
	EBSCO and SPORTDiscus	85
	Web of Science	33
	Google Scholar	40

Data extraction

From the manuscripts selected, we recorded authors' names, year of publication, study design (i.e., cross-sectional or longitudinal), study context (i.e., training or competitive performance environments), sample characteristics, the specific sport context, variables assessed, type of constraints manipulated (i.e., task, athlete, and environment), statistical methods, and main findings. Studies which did not afford enough appropriate information to conduct a meta-analysis were still assessed for methodological quality and reported in the review summary table (see Appendix 1).

Study quality assessment

The assessment of methodological quality of the studies included was completed through the validated Downs and Black checklist (Downs & Black, 1998). This scale offered us the possibility to emphasise the strongest and weakness points of each study under assessment, as well as to evaluate cross-sectional and longitudinal study designs (Bento, 2014). The studies rates were discussed among the research team (first author and co-authors), with discussion and agreement for any observed differences. Specifically, the checklist encompasses 27 items that are intended to evaluate the reporting, validity, and statistical power of the published reports. Specifically, items 1-10 refer to reporting, items 1-13 related to external validity, items 14-26 refer to internal validity, and item 27 addresses the statistical power. Study quality was classified according to the methods of Grgic et al. (2018), where the studies were categorized as “good quality” if they scored 20-29 points, “moderate quality” between 11-20 points, and “poor quality” if < 11 points.

<u>Meta-Analysis Procedures</u>

Data Analysis

The effect size measures for each variable identified were standardized through measures of mean and standard deviations, correlations coefficients, Cohen’s d values, and t-test values. Considering the methodological differences across studies (i.e., sample, and statistical procedures) a random effect model was used as recommended by Field and Gillett (2010). The values of effect size were interpreted as > 0.2 (small), > 0.5 (moderate), and > 1.2 (large) (Cohen, 1988).

The heterogeneity across the studies was assessed using Q-test and quantified through I^2 statistics. The I^2 is a quantitative measure of inconsistency among studies, which describes the percentage of total variation across studies attributed to heterogeneity, rather than chance (Higgins, Thompson, Deeks, & Altman, 2003). The I^2 could be quantified as <25% (homogeneous), 25%-50% (low), 50%-75% (moderate), and >75% (high) (Higgins et al., 2003). Further, the estimation of publication bias was assessed through a rank correlation test (Begg & Mazumdar, 1994), and Egger's test (Egger, Smith, Schneider, & Minder, 1997). Publication bias consists of considering only studies that reported statistically significant outcomes ($p < 0.05$), removing from the literature studies which may have observed statistically non-significant findings, including false negatives. All tests were set with a statistical significance level of $\alpha = 0.05$. The entire data set was transformed and computed in the Comprehensive Meta-Analysis software package, 2008 (BioStat, Englewood, New Jersey).

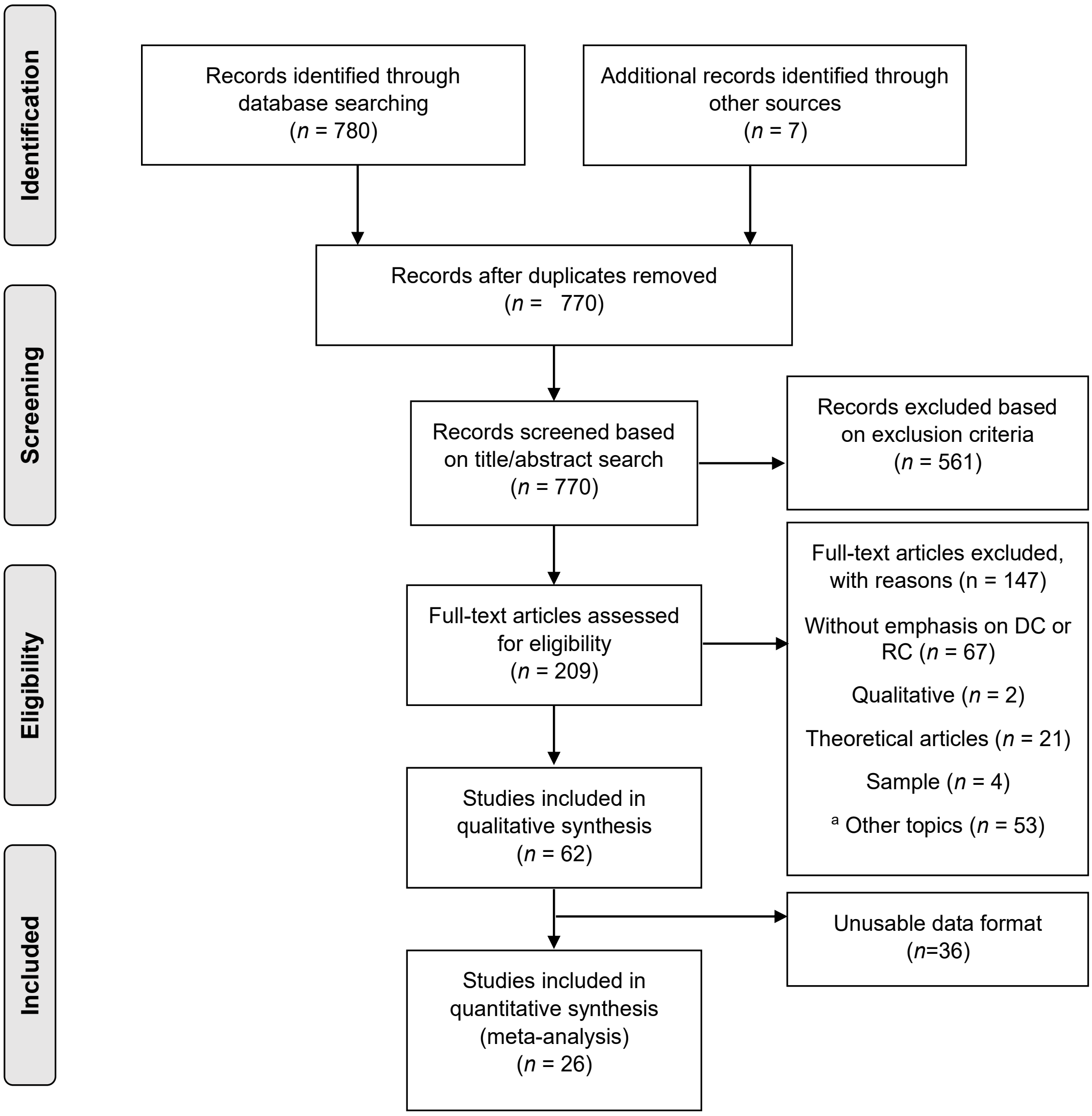
Moderator variables – Subgroup analysis

Among the four synergetic properties discussed in the study by Araújo and Davids (2016), the properties of dimensional compression and reciprocal compensation have received the most investigative analysis in contemporary research. For that reason, we selected them as potential moderator variables during the subgroup analysis. In line with the recommendations of Araújo and Davids (2016), measures of geometric centre (or centroid, or weight centroid), stretch index (or relative stretch index), effective playing space (or surface area, or convex hull), team spread, team width, team length, and team length per width ratio were codified as dimensional compression properties (i.e., first moderator). The reciprocal compensation properties (i.e., second moderator) included measures of relative phase, cluster phase, and running correlations.

Results

Studies selection

The stages of the search and the study selection process are presented in Figure 1. Globally, 62 studies were included in the systematic review and 26 met the inclusion criteria for the meta-analysis.



[a] Other topics – pilot, case studies or studies that present variables and concepts under analysis that there are not within the scope of CLA.

Figure. 1. Flow chart of study selection process based on PRISMA (Moher et al., 2015)

Studies Characteristic

The general characteristics of studies included in qualitative and quantitative analyses are summarized in Table 2. Regarding study design, it was observed that the publications selected in both, qualitative and quantitative analyses, implemented mainly cross-sectional designs, with common experimental protocols applied within training environments. A prevalence for analysis of performance in samples of male participants was also observed and studies mainly focused on team sports of football and futsal, as well as rugby union, basketball, and tennis. Constraints related to practice task design were most frequently manipulated, followed by those in the environment and individual (organismic) categories.

Table 2. General characteristic of studies included in qualitative and quantitative analysis

Study design		**Study context**		**Sample**			
Cross-sectional	Longitudinal	Training	CPE	Male	Female	[a] Official matches	[a] Players
55 (24)	7 (2)	44 (21)	19 (5)	48 (20)	3 (1)	3 (1)	11 (4)
Sport							
Basketball	Tennis	Football	Futsal	Rugby	Modified throw and catch game		
5 (1)	2	39 (22)	8 (2)	3	1 (1)		
Swimming	Field Hockey		Long Jumping		Cricket		
1	1		1		1		
Type of constraints manipulated							
Task			Player		Environment		
42 (18)			13 (6)		19 (6)		

Notes: CPE – Competitive Performance Environment; The numbers outside parenthesis correspond to values of studies included in the systematic review. The numbers inside parenthesis correspond to values of studies included in the meta-analysis.

[a] Studies that did not specify the participants' sex.

Methodological Quality

Both the systematic review and meta-analysis followed the same methodological quality trends. Thus, the average score on the Downs and Black checklist was 13 (range 10-16). One study was assessed as methodologically poor, while the remaining investigations were evaluated as having moderate methodological quality. None of the studies included were classified as being of good methodological quality. Regarding the studies included in the meta-analysis, the average score was 13 (range 10-15). Further analyses revealed the presence of publication bias, with statistically significant values being observed in outcomes of Begg's ($p = .006$) and Egger's ($p = .03$) tests.

Meta-analysis of outcome measures

The meta-analysis results regarding assessment of team synergetic properties are presented in Table 3 and Figure 2. A significantly high level of heterogeneity among the studies selected was observed (I^2 = 99.56%, p < .001), with a summary effect value of 0.17.

Meta-analysis of subgroup analysis

Table 3 also shows significant values (p = .001) for the moderator variables, indicating that these were suitably selected. However, the heterogeneity values remained significantly high (I^2 = 99.56%), meaning that the differences across studies (i.e., differences in analyses of teams' synergies) are not fully explained by each of the two synergetic properties (dimensional compression and reciprocal compensation) (see Table 3). Following the recommendations of Field and Gillett (2010), an additional exploratory analysis of heterogeneity was performed with the purpose of finding other moderators variables which could possibly explain the high heterogeneity values. Accordingly, the geometric centre values in teams studied in the sport of Football were analysed due their frequency of analysis in the sample. However, a huge decrease in heterogeneity values was not observed (i.e., I^2 = 96,86%, p < .001, with an effect size of 0.74).

Table 3. Test of the meta-analysis models and the respective moderators for each model.

	Effect size and 95% confidence interval						Test of null hypothesis (2-tailed)		Heterogeneity			
Model	**Number of studies**	**Point estimate**	**Standard error**	**Variance**	**Lower limit**	**Upper limit**	**Z**	**p**	**Q**	**df(Q)**	**p**	**I^2**
Random	26	0.17	0.23	0.05	-0.27	0.61	0.75	0.455	5669	25	0.001	99.56
Sub-Groups Analysis												
	Effect size and 95% confidence interval						Test of null hypothesis (2-tailed)		Heterogeneity			
Groups	**Number of studies**	**Point estimate**	**Standard error**	**Variance**	**Lower limit**	**Upper limit**	**Z**	**p**	**Q**	**df(Q)**	**p**	**I^2**
Fixed effect analysis												
Dimensional Compression	17	0.09	0.02	0.001	0.04	0.12	3.99	0.001	467.64	16	0.001	96.58
Reciprocal Compensation	9	1.4	0.01	0.001	1.38	1.43	129.23	0.001	1993.24	8	0.001	99.65
Total within									2460.88	24	0.001	
Total between									3208.12	2	0.001	
Overall	26								5669	25	0.001	99.56

Study name	Subgroup within study	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Aguiar et al., (2015)	Combined	-1,042	0,117	0,014	-1,271	-0,813	-8,906	0,000
Baptista et al., (2018)	Combined	-1,986	0,283	0,080	-2,541	-1,430	-7,009	0,000
Bueno et al., (2018)	Combined	0,191	0,037	0,001	0,118	0,265	5,116	0,000
Castellano et al., (2017)	Combined	0,148	0,134	0,018	-0,115	0,410	1,104	0,270
Coutinho et al., (2017)	Combined	-0,599	0,156	0,024	-0,905	-0,292	-3,831	0,000
Duarte et al. (2012)	Combined	0,667	0,342	0,117	-0,004	1,338	1,948	0,051
Duarte et al. (2013)	Combined	1,975	0,283	0,080	1,420	2,529	6,977	0,000
Folgado et al., (2018) a	Combined	0,628	0,102	0,010	0,427	0,829	6,132	0,000
Folgado et al., (2018) b	Combined	0,492	0,192	0,037	0,116	0,869	2,564	0,010
Frencken et al. (2012)	Combined	5,015	0,631	0,399	3,778	6,252	7,944	0,000
Gonçalves et al. (2014)	Combined	-0,097	0,447	0,200	-0,974	0,780	-0,216	0,829
Gonçalves et al. 2019	Combined	0,100	0,031	0,001	0,039	0,160	3,240	0,001
Gonçalves et al., (2016)	Combined	-0,815	0,403	0,162	-1,605	-0,026	-2,024	0,043
Gonçalves et al., (2017) b	Combined	-0,312	0,109	0,012	-0,526	-0,099	-2,871	0,004
Gonçalves et al., (2018) a	Combined	-8,382	0,269	0,073	-8,910	-7,854	-31,125	0,000
Gonçalves et al., (2018) b	Combined	4,092	0,387	0,150	3,333	4,851	10,566	0,000
Laakso et al., (2017)	Combined	-0,791	0,130	0,017	-1,047	-0,536	-6,078	0,000
Memmert et al. 2019	Combined	-0,014	0,127	0,016	-0,263	0,236	-0,107	0,915
Olthof et al., (2015)	Combined	3,588	0,362	0,131	2,879	4,297	9,913	0,000
Ribeiro et al. 2019	Combined	0,104	0,189	0,036	-0,267	0,474	0,549	0,583
Silva et al. (2014a)	Combined	-0,009	0,163	0,027	-0,329	0,311	-0,056	0,956
Silva et al., (2015)	Combined	-0,114	0,118	0,014	-0,345	0,117	-0,966	0,334
Silva et al., (2016) a	Combined	0,051	0,091	0,008	-0,128	0,230	0,559	0,576
Tan et al., (2017)	Combined	1,472	0,011	0,000	1,450	1,494	132,648	0,000
Travassos et al., (2014) a	Combined	-0,264	0,192	0,037	-0,640	0,111	-1,380	0,167
Travassos et al., (2014) b	Combined	1,714	0,396	0,157	0,937	2,491	4,325	0,000
		0,169	0,226	0,051	-0,274	0,612	0,747	0,455

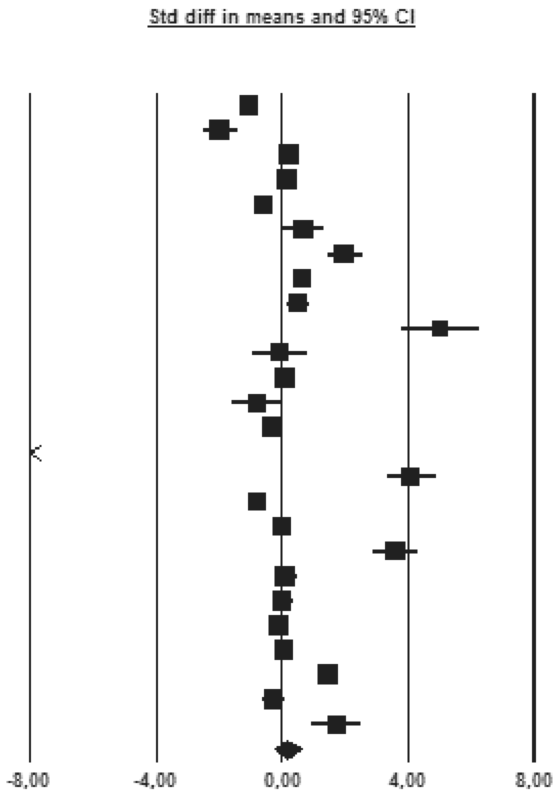


Figure 2. Forest plot regarding to analysis of team synergetic properties

Discussion

The current study sought to quantify and compare research findings related to the dimensional compression and reciprocal compensation synergetic properties in sports teams, shaped by interacting player, task, and environment constraints. Overall, cross-sectional designs were typically used in the literature to explore how the manipulation of different task constraints may affect the tactical behaviours of male players' and/or teams within training sessions. A high level of heterogeneity was observed across the studies selected for meta-analysis, possibly due to the diversity of methodological and statistical procedures used. The sub-group analysis showed that the moderator variables were suitably selected. However, the heterogeneity values remained significantly high, indicating that differences across the studies are not completely explained by each of the two synergetic properties considered.

Considerations regarding study designs and contexts

Results indicated that cross-sectional designs were the most frequently used. Corroborating the results reported by Ometto et al. (2018), few longitudinal studies were found, possibly due to the difficulties in collecting data across several occasions in team training schedules (Caruana, Roman, Hernández-Sánchez, & Solli, 2015). Typically, cross-sectional studies have analysed the impact of training protocols, in which task constraints were manipulated, on adaptative capacities of players and teams. Despite the undeniable contribution of these investigations, they only afford an "end-product" perspective (i.e., comparing how players started and ended, after the practical intervention) (e.g., Machado et al., 2019; Ribeiro et al., 2019). Analysis of the process underlying to the influence over time of constraints manipulations, however, requires a longitudinal overview. In general, the few longitudinal studies that did explore collective behaviours focused their analyses on team coordination tendencies, showing that team coordination is grounded on the formation of synergies between players (e.g., Silva et al., 2016), as well as suggesting that, when variability of performance contexts increased, speed of team coordination decreased (Gonçalves et al., 2018). However, as suggested by Silva et al. (2016), to develop an understanding of team collective behaviours, future research also requires an analysis of team asymmetric patterns, since they may represent a specific team strategy.

Concerning study contexts, compared to those undertaken in the competitive performance environment, almost three times the number of studies were conducted within training contexts. In this sense, more studies focused on the analysis of collective system behaviours in competitive performance contexts are needed next. In fact, the competitive performance environments entail unique characteristics, under which players are continuously constrained to adapt their tactical behaviours. In other words, competitive environments provide a valid performance evaluation for players and teams, providing reliable information about their tactical behaviours (Eccles, Ward, & Woodman, 2009). Therefore, as shown by Woods and colleagues (2019), information obtained from performance analytics in a competitive environment, provides a fundamental basis for designing weekly training programs in high performance sport. Their research showed how evidence from analysis of previous competitive matches is extremely useful to build specific representative learning scenarios during training sessions. They showed how, based on the needs of individual players or sub-groups of players in the team, different constraints can be manipulated to afford design informational constraints and affordances in practice which simulate those recorded in competition (enhancing representativeness).

Furthermore, most cross-sectional investigations of team performance in training sessions have failed to explain why different constraints manipulations were integrated and implemented in practice, and what individual or collective problems (i.e., technical, tactical, etc.) were targeted (Correia et al., 2012; Gonçalves et al., 2017). Moreover, usually such protocols are implemented during a small part of the training session, without the provision of information about intersections with the other parts of organized training programs (Esteves et al., 2012; Silva et al., 2014).

Considerations regarding gender and type of sport

Typically, samples of male team-sport athletes were investigated, with only one study integrating females and males within the same sample. This seems to represent the current sex bias that is intrinsic in sport science research on team games performance. This bias was recently highlighted by Gentile, Boca, and Giammusso (2018), who reaffirmed that despite the number of women taking part in traditionally male sports has been growing, stereotyping based on sex differences persists in sport. To reverse this trend, an increase in the number investigations seeking to evaluate effects of constraints manipulation on performance of female participants in sports is needed. This is especially important given the continuing rise in popularity of women's competitions in many team games like Association Football (soccer) and Rugby Union (Fraser, 2019). Furthermore, the physical and maturational differences between females and males at different ages (Cumming, Standage, Gillison, & Malina, 2008; Ramos et al., 2018) could lead to variations in responses to constraints manipulations during practice. This effect should be investigated more thoroughly so that it can be taken into serious consideration by practitioners in the design of learning tasks.

Regarding the type of sports researched to date, possibly due to their global popularity and “media coverage” and/or due to convenience sampling, invasive team games (particularly football) have been most frequently investigated. A large body of work has provided information about how players cooperate and co-adapt their tactical behaviours, extending our understanding of tactical playing patterns in invasive games (e.g., Folgado, Lemmink, Frencken, & Sampaio, 2014). However, knowledge about how collective synergetic properties emerge, persist, and evolve in non-invasive sports (i.e., activities with indirect interdependence among opponents, who compete between each other to accomplish competitive performance goal (Evans et al., 2012)) remains scarce.

Considerations regarding type of constraints manipulated

In agreement with the outcomes of studies by Aguiar, Botelho, Lago, Maças, and Sampaio (2012) and Ometto et al. (2018), our results depicted that the most typically manipulated constraints were related to the specific task undertaken, followed by environmental and organismic (athlete) constraints. Specifically, the most frequently manipulated task constraints were related to playing area dimensions (i.e., pitch size and practice spaces), numerical relations between players in different teams (i.e., using equal and unequal numbers of players in competing teams), and the imposed rules of practice matches. The studies where playing dimension and space were manipulated revealed that larger playing areas promoted higher levels of variability in player movements (Silva et al., 2014), more opportunities for creating overloads (gaining numerical advantage) (Silva et al., 2015), higher levels of physical performance (Olthof et al., 2017), as well as an elongated team playing shape (Silva et al., 2014). Moreover, studies focusing on the role of manipulating player numbers involved in SSCGs suggested that numerical relations between teams clearly constrained intra-team coordination, mainly in situations of numerical disadvantages between competing teams (Silva et al., 2014; Travassos, Vilar, Araújo, & McGarry, 2014). Finally, Silva et al. (2014) found that players and teams self-organized according to the specific game rules applied during SSCGs.

There are two reasons behind the significant research interest in manipulating task constraints. First, there is a consensual idea that breaking the full game into smaller phases or tasks (for instance, practicing technical or tactical tasks within a specific game sub-phase) guides learners' attentional focus to enhance their understanding and performance (Ford, Yates, & Williams, 2010; Travassos, Duarte, Vilar, Davids, & Araújo, 2012). Second, interpretations of Newell's constraints model (Newell, 1986) with reference to team sports performance (e.g., Handford, Davids, Bennett, & Button, 1997), have suggested that organismic constraints (of players) concern physical characteristics of each player (e.g., morphological characteristics), while environmental constraints encompass how physical and social conditions influence performance (e.g., weather and crowd size) (Renshaw & Chow, 2019). In this sense, task constraints have been considered the easiest, and most important, to manipulate by sport practitioners, as revealed in past research analyses (Ometto et al., 2018).

Considerations regarding team synergetic behaviours

Generally, investigations have claimed that synergies (often referred as couplings between individuals) form the basis of interpersonal coordination tendencies in team sports (Duarte et al., 2012), which emphasizes their pertinence for study. To date, most studies have analysed the property of dimensional compression, especially focusing on low dimensional variables. For instance, Gonçalves et al. (2018) identified changes in effective playing space, considering the manipulation of the number of players involved (ranging from 3 to 10). They concluded that increasing the number of players involved in SSCGs influenced both regularity and absolute effective playing space areas. In line with this finding, similar studies have suggested that players are able to functionally co-adapt (i.e.., self-organize) their behaviours in response to manipulation of several task constraints (e.g., Fitzpatrick, Davids, & Stone, 2016; Oppici, Panchuk, Serpiello, & Farrow, 2018; Tan, Chow, Duarte, & Davids, 2017).

Aligned with the arguments of Araújo and Davids (2016), few studies have focused on the analysis of the reciprocal compensation property of teams. These studies have focused attention on the degree of synchronization between players, using relative phase, running correlations and cluster phase analysis. Studies of reciprocal compensation have revealed a mutual influence on the synchronization tendencies between teams, particularly decreased intra-team coordination when teams are losing, better coordination tendencies in defensive lines, as well as synchronic tendencies between the players and ball and players and an immediate marker (Duarte et al., 2013; Folgado, Duarte, Marques, Gonçalves, & Sampaio, 2018; Vilar et al., 2014).

Considerations regarding statistical methods

Throughout the analysis of the studies selected for systematic review, we identified a vast and distinct number of metrics applied, suggesting that there is a methodological adjustment according to the sport and the synergetic property under analysis. As identified by Araújo, Silva, and Ramos (2014), our analysis showed that the property of dimensional compression has been captured through analysis of the variable “team centre” (e.g., weight centroids) and team dispersion metrics (e.g., stretch index, effective playing space, team spread). Concerning the analysis of reciprocal compensation, initially studies focused on the analysis of dyads (1v1s), through using the relative phase method (Duarte et al., 2010). However, the need to explain how actions of different players become synchronized within the collective behaviours of a team have led to favouring a distinct metric – the cluster phase method, based on the Kuramoto order parameter (Duarte et al., 2013). Nowadays, the exploration of hypernetworks seeks to simultaneously observe the cooperative and competitive interactions between teammates and opponents across the space-time scale during a competitive match (e.g., Ramos, Lopes, Marques, & Araújo, 2017; Ribeiro et al., 2019).

Indeed, a deep analysis of complex system behaviours cannot be assessed through using simple linear measures, and for that reason the use of several sophisticated non-linear measures has been applied in the sport sciences (Silva, Duarte, Esteves, Travassos, & Vilar, 2016). Despite their undeniable contribution, such methodological diversity has made it challenging to identify patterns of behaviour and interpret the main findings across studies. Therefore, in order to enable a comparison of the main findings between studies, future investigations should combine non-linear metrics with linear (traditional) methods (e.g., Ribeiro et al., 2019). Through these combined methodological approaches, it would be possible deepen understanding of the processes underlying synergetic behaviours, as well as to integrate the main findings into a quantitative review.

Considerations regarding the meta-analysis

The meta-analysis results of our study portrayed a high level of heterogeneity across studies. As expressed by systematic analysis results discussed above, the assessment of several sports, distinct populations, the diversity of variables under analysis, the use of a wide range of different metrics in statistical procedures and the manipulation of different constraints, could possibly have contributed to this outcome.

In addition, the subgroup analysis did not reveal differences in heterogeneity levels, possibly because several metrics could be used to assess each synergetic property, in agreement with the reasons mentioned above. Notwithstanding, the quantitative analysis performed in this study evaluated players' behaviours, which dynamically emerged under different manipulations of practice task constraints. This viewpoint is supported by data from the literature on CLA, whereby greater variability of tactical behaviours in players provide them with an opportunity to self-organize and co-adapt to any context with the purpose of satisfying emerging performance or task demands (Passos et al., 2009; Paulo, Davids, & Araújo, 2017; Travassos et al., 2016). Therefore, the heterogeneity found between the selected studies possibly supports the assumption that variable scenarios promote flexible behaviours which, in turn, afford adaptable actions. Accordingly, the heterogeneity found in our analysis, besides being unexpected, seems to be positive, desirable, and functional. However, with the aim of confirming this hypothesis, we strongly encourage the replication of some experimental protocols in future investigations (i.e., applying the same intervention protocol in similar samples under the same testing conditions).

Finally, the presence of bias could possibly reflect both publication and inflation bias within this research field. The publication bias consists of considering only studies that provide statistically significant results (i.e., $p < .05$) (Simonsohn, Nelson, & Simmons, 2014). This decision may have removed from the literature base studies where results may have not confirmed hypotheses or were considered negative, including false negatives. Inflation bias concerns the exhaustive exploration of data using different statistical approaches, which introduces in the literature true or false positives (Head, Holman, Lanfear, Kahn, & Jennions, 2015). This finding highlights the need to take some methodological care in future academic studies in order to reverse this trend, otherwise this may lead us towards overoptimistic (and false) conclusions. Thus, we strongly suggest that future investigations report non-significant effects and share the statistical procedures conducted across investigations. Furthermore, despite the relevance, and the deep contributions afforded by the studies in the current analyses, a further challenge it to evaluate team synergetic properties during competitive performance, according to the specificities of different team sports (e.g., invasive versus non-invasive sports). Also, there is a lack of research identifying reliable predictors for the adaptation of synergetic team behaviours (e.g., maintaining, or winning possession of the ball, according to changes in current match status).

Limitations of the current study

Several limitations may be acknowledged in the present investigation. First, it is plausible that some published literature may not have been identified, even following all the comprehensive searches of databases and systematic steps reported. Second, several studies did not report suitable measures (e.g., degrees) to perform a meta-analysis. For instance, studies that aimed to evaluate the reciprocal compensation properties used mostly relative and cluster phase analysis, metrics expressed in degrees, where values near zero degrees expressed in-phase states and degrees near 180º signified anti-phase states. Also, several studies used Analysis of Variance (ANOVA) and Multivariate Analysis of Variance (MANOVA) for statistical analysis of the data, without reporting the eta-square measure or descriptive measures, not providing effect size calculations. With this statistical approach, missing information, in both qualitative and quantitative reviews, might influence aforementioned assumptions concerning the state of art in this research field (e.g., McCosker, Renshaw, Russell, Polman, & Davids, 2019). Particularly, the exclusion of several investigations due to an unsuitable or unreported data format might limit the results observed in the present study. Finally, when the designs across studies included in meta-analyses were heterogeneous, we tried to counter this issue by employing a random-effects model (Higgins, 2008) and performing different explorative sub-group analyses. For this reason, the results should still be interpreted with caution.

Conclusions

This study summaries, compares and quantifies the findings related to dimensional compression and reciprocal compensation properties both shaped on constraints manipulation. Results from the systematic review suggested that cross-sectional investigations have focused on evaluating how the manipulation of task constraints may affect male football players and teams during training sessions. Additionally, the analysis of team synergetic properties has been undertaken through vast and distinct metrics, with dimensional compression analysis receiving more attention in the literature. Results from the quantitative review portrayed high heterogeneity values among the studies selected, possibly due to the diversity of statistical procedures applied to measure team synergetic properties. This observation possibly supports the assumption that variable behaviour, as a response to the manipulation of different constraints, offers opportunities for adaptability in the tactical behaviours of team players. Therefore, such heterogeneity may be functional and desirable. Integrating the findings from both, qualitative and quantitative reviews, we conclude that more investigations are needed to adopt longitudinal designs, in which synergetic behaviours of female players are assessed during a competitive performance season in non-invasive team sports. Finally, we conclude that there is a presence of publication and inflation bias within this research field, which highlighted the need for researchers to take more methodological care in future investigations, particularly to pay more attention to statistically non-significant outcomes.

As our findings emphasized, there is a lack of investigations of female players' behaviours during competitive performance. In addition, there is also a dearth of studies that have compared evaluations of the players' behaviours during competitive performance with those observed in specific and representative learning designs during training sessions (i.e., action fidelity analysis, see Travassos et al. (2012)). Therefore, we recommend this type of analysis in future research. This type of investigation will offer the opportunity to evaluate the quality of practice designs. Here, an action-research design could fit well with this purpose. For instance, an action-research design implemented throughout a competitive season would enable to examine how collective synergetic properties can be developed (e.g., Ramos, Coutinho, Davids, & Mesquita, in press). Furthermore, future studies should present an appropriate contextualization of constraints manipulation inside the whole training process (i.e., why, and how, are the specific constraints manipulated? What technical/tactical problem does the manipulation seek to resolve?). This approach would clearly inform, both academics and coaches, about how to use several pedagogical strategies to optimize the holistic development of players and teams.

In practical terms, based on our findings, we recommend that coaches integrate and manipulate different task constraints since they might induce variable collective tactical behaviours in learners. However, we highlight the need to manipulate the learning tasks according to specificities of: (i) different sports, (ii) the tactical and technical problems that need to be resolved, and (iii), experience and competitive performance levels of learners.

Appendix 1. Summary of data extraction from studies included on systematic review and meta-analysis.

Authors (year)	Study Design	Study Context	Sample (N)	Sport	Variables Assessed	Type of Constraints Manipulated	Statistical Methods	Main Findings	Downs & Black Scale
Palut and Zanone (2005)	Cross-sectional	Training	Players (n= 4)	Tennis	Spectral analysis, Relative phase	Task - rules	Relative phase	There were two stable patterns of synchronization, in-phase and anti-phase, as the players moved in the same or opposite directions, respectively	14
Bourbousson et al. (2010a)	Cross-sectional	CPE	Male basketballers (n=6)	Basketball	Intra and inter couplings among dyads, Lateral displacement, Phase relations, Phase stabilities, Phase transitions	Task - space and time restrictions	Relative phase	Strong in-phase relations in the longitudinal and lateral direction were observed for all playing dyads, indicating that these movements were very constrained by the game demands	14
Bourbousson et al. (2010b)	Cross-sectional	CPE	Male basketballers (n=6)	Basketball	Spatial centres, Stretch index, Relative stretch index	Task - space and time restrictions	Relative phase	There was a reciprocity between teams in their amounts of expansion and contraction when possession of the ball is won and lost.	14
Pedro Passos et al. (2011)	Cross-sectional	Training	U18 Male players (n=16)	Rugby	Functional interpersonal distance, Players' interpersonal coordination, Strength of coupling	Task - numerical relations - interpersonal distance	Running correlations Regression	Grouping tendencies in attacking subunits of team games are sensitive to different task constraints relative positioning to nearest defenders	16
Travassos et al. (2011)	Cross-sectional	Training	Male players (n=15)	Futsal	Ball dynamics, Coordination dynamics between defenders (or attackers) and ball, Intra-team coordination for defending and attacking, Inter-team coordination for defender-attacker	Task - field dimension (half of pitch size)	Relative phase ANOVA	The dynamic patterns are generated within functional constraints, with players and teams exerting mutual influence on each other	14
*Duarte et al. (2012)	Cross-sectional	Training	U13 Male (n=14)	Football	Surface area, Centroid, Key moments of play, Coordination tendencies	Environment - key moments of play - competitive context Task - rules (way to score)	Running correlations ANOVA	The major changes in sub-group behaviours occurred just before an assisted pass was made, leading to a loss of stability in the 3 vs 3 sub-phases	13

Esteves et al. (2012)	Cross-sectional	Training	U16 Male basketballers (n=4)	Basketball	Longitudinal and lateral displacements, Relative positioning of attacker–defender dyads to the basket	Task - space (delimitation of relative positions to the basket)	Mann-Whitney	Interpersonal coordination tendencies changed according to the scaling of the relative position of performers to the basket	16
*Frencken et al. (2012)	Cross-sectional	CPE	Male players (n=25)	Soccer	Longitudinal and lateral inter-team distances, Team centroid, Critical match periods	Environment - key moments of play - competitive context	Pearson correlations Chi-Square	Periods of highly variable inter-team distance were associated with collective defensive actions and team reorganisation in dead-ball moments rather than goals or goal attempts	14
Travassos et al. (2012c)	Cross-sectional	Training	Male players (n=15)	Futsal	Patterns behaviours, Player configurations, Ball kinematics, Goal being attacked, Goal being defended	Task - extra outfield player	Relative phase ANOVA	Ball kinematics is a key constraint that influences the dynamical behaviours of the players and teams	13
Vilar et al. (2012)	Cross-sectional	CPE	Official matches (n=10)	Futsal	Coordination period, Distance to goal, Angle to goal, Distance to ball, Angle to ball	Environment - competitive context - distances and angles to goal	Relative phase ANOVA	The location of the ball did not appear to exert as much of an influence on coordination of players in dyadic systems as did location of the goal	14
Carvalho et al. (2013)	Cross-sectional	CPE	Official matches (n=27)	Tennis	Players' positional advantage, Players' interpersonal coordination, Rallies breaks	Environment - competitive context - relative position of players	Wilcoxon signed rank test	The relative positioning of players on the court constrained the dynamics of their performance. Through the quantification of positional advantage was possible to identify and describe the emergence of scoring	13
*Duarte et al. (2013)	Cross-sectional	CPE	Male players (n=28)	Football	Team-team synchronization, Player-team synchronization, Ball possession, Game halves, Team status, Field direction	Environment - competitive context - key moments of play	Bivariate correlations ANOVA	The increase of synchronization in one team were concomitantly accompanied by increments in the opposing team, indicating the mutual influence of synchronization processes	13
Vilar et al. (2013a)	Cross-sectional	CPE	Male players (n=28)	Football	Sub-areas of play, Distribution of players, Inter-team coordination, Unpredictability of inter-team coordination, Internal team coordination	Environment - competitive context - numerical dominance	Frequency histograms	Each specific player abilities contribute within the context of the dynamics of multiplayer team coordination and coaching strategy	12

Bourbousson et al. (2014)	Cross-sectional	CPE	Male players (n=10)	Basketball	Dyadic attacker-defender, Inter-team dynamical relationship, Relative phase of geometrical centre and stretch indexes, Relative stretch index between teams, Time period, Field direction	Environment - competitive context	ANOVA	The action of a drive in a real competitive basketball game was grounded in teammates' and their opponents' movements, especially the dynamics of the relationships between the teams	11
Folgado et al. (2014)	Cross-sectional	Training	Male players (n=30)	Football	lpwRatio, Centroid distances, Age group, SSG formats	Player - age groups (U9, U11, U13) Task - numerical relations (3v3, 4v4)	ANOVA	The collective variables (lpwRatio and centroid distances) revealed appropriate to understand the tactical implications SSG.	13
*Gonçalves et al. (2014)	Cross-sectional	Training	Male players (n=20)	Football	Centroid of defenders, midfielders and forwards, Absolute distances, Speed, Heart-rate, Body load	Player - field position	ANOVA	All players (defenders, midfielders and forwards) were nearer and more coordinated with their own position-specific centroid	13
Sampaio et al. (2014)	Cross-sectional	Training	Male players (n=24)	Football	Distance covered and time spent, Heart rate, Centroid distance, Numerical relations, Match status	Task - numerical relations (5v4, 4v5) Environment - match status	ANOVA	Practice task design manipulating game pace, status and team unbalance significantly influenced the emergent behavioural dynamics	13
*Silva et al. (2014a)	Cross-sectional	Training	Male players (n=20)	Football	Field dimension, Skill level, Effective playing space, Playing length per width ratio, Team separateness, Teams centroids'	Players - expertise level Task (4v4) - rules - field dimension	ANOVA	SSCGs played on fields of different dimensions constrained behaviours in both skill levels. The more skilled players tended to adapt differently to the SSCGs since, they assumed an elongated playing shape when the playing area increased.	13
Silva et al. (2014b)	Cross-sectional	Training	Male players (n=20)	Football	Inter-individual coordination (major ranges), Intra-team coordination (stretch index and centroids' distance to own goal and mini-goals' line), Inter-team coordination, Expertise level, Numerical relations	Players - expertise level Task - numerical relations (5v5, 5v4, 5v3)	ANOVA	Individual and team coordination were constrained by the numerical relations and players' skill level, highlighting the importance of adapting training tasks to the players' individual characteristics	13
*Travassos et al. (2014a)	Cross-sectional	Training	Male players (n=20)	Futsal	Pitch conditions, Centre of gravity, Stretch index, Relative stretch index	Task (5v5) - number of targets (2 vs 6)	Cohen's d	The manipulation of the number of scoring targets demands adaptations between teams on the spatial–temporal relations and the	12

								pitch locations that teams used to explore their relations as well.	
*Travassos et al. (2014b)	Cross-sectional	Training	Male players (n=15)	Football	Game condition, Geometric centre, Couplings between players, teams and between players-teams and ball	Task - numerical relations (5v5, 5v4)	Relative phase ANOVA	Changes in the couplings and coordination patterns were observed between players and teams, particularly for the defending players and teams under condition of numerical disadvantage	14
Vilar et al. (2014a)	Cross-sectional	Training	Male players (n=71)	Futsal	Distance of attackers to the defenders, goal, and ball,	Task - relative position of defenders - relative distance to goal	Relative phase ANOVA	Distances of attackers to the goal and ball, and distances of ball carriers to defenders, seemed to be coupled in a specific manner to guide interpersonal coordination tendencies between players during competitive performance	15
*Aguiar et al. (2015)	Cross-sectional	Training	U19 Male players (n=10)	Football	Team centroid, Distance between each player and own and opponent team centroid, Distance between centroids	Task - SSG formats (2v2, 3v3, 4v4, 5v5)	Cohen's d	The 4v4 and 5v5 formats are preferred to achieve team-related emergent and self-organised behaviour, as they showed higher predictability in positional inter-team coordination	12
*Olthof et al. (2015)	Cross-sectional	Training	Male players (n=39)	Soccer	Longitudinal and lateral: Inter team distances, Stretch indices and lpwRatio, Centroid positions, Age categories	Players - age groups (U17, U19)	Cohen's d	Under-19 adopted a wider pitch dispersion than Under-17, represented by a larger lateral stretch index and smaller lpwRatio	14
*Silva et al. (2015)	Cross-sectional	Training	U15 Male players (n=24)	Football	Effective relative space per player, Radius of free movement, Numerical relations inside each player's relative space per player, Players' spatial distribution variability, Field dimension, Players number	Task - numerical relations (6v6, 7v7, 8v8, 9v9) - field dimensions	Cohen's d	Manipulations of player numbers elicited more free space in the vicinity of each player. Advantageous numerical were observed during manipulations of field dimensions	15
Castellano et al. (2016)	Cross-sectional	Training	Male players (n=24)	Soccer	Length, Width, Team shape, Team separateness, SSGs formats, Playing phase	Task - size of goal - with and without goalkeepers - floaters	Cohen's d	The strategies adopted by teams revealed different coadaptation patterns during attacking and defending phases where, the key principles regarding the spread of players were preserved as a function of having the ball or not, whatever the constraints that were acting upon the players	12

Vanda Correia et al. (2016)	Cross-sectional	Training	U12 Male players (n=8)	Rugby	Performance outcomes, Interpersonal coordination, Movement velocity, Performance outcome	Task (1v1) - key performance outcomes	ANNs Running and cross-correlations	There were distinct coupling patterns that result in different performance outcomes, adding evidence for how players create and perceive possibilities for action while seeking to attain specific performance goals	13
*Goncalves et al. (2016)	Cross-sectional	Training	Male players (n=44)	Football	Expertise level, Type of scenario, Effective playing space, Absolute distances from each player to the team centroid and opponent centroid, Distance from each player to the nearest opponent	Task - numerical relations (4v3, 4v5, 4v7) Players - level of expertise	Cohen's d	Teammates seemed to dynamically adapt their behaviours with the ecological games context and better understand the positioning informational demands of the task constraints	12
*Silva et al. (2016a)	Longitudinal	Training	Male players (n=29)	Football	Dimensional compression, Team Couplings, Couplings between teammates, Reciprocal compression	Task (11v11) - rules	Determination Coefficients	Team movements are grounded on the formation of synergies, responsible for linking actions of teammates during synchronized rhythmic movements	11
Silva et al (2016b)	Cross-sectional	Training	U15 Male players (n=10)	Football	Players' dispersion, Team separateness, Time delay between team movements, Coupling strength, Number of players	Task - numerical relations (3v3, 4v4, 5v5)	Intraclass correlation	Team tactical behaviours were adapted to decreases in relative space per player values, through increases in players' dispersion in order to maintain space, what suggests the view of a team as adaptive system's degeneracy	12
*Castellano et al (2017)	Cross-sectional	Training	Male players (n=28)	Soccer	SSG formats, Players age, Team length and width, Convex hull, Stretch index	Task (7v7) - pitch length (60m, 50m, 40m, 30m) Player - age group	Cohen's d	Teams coadapted differently according to pitch length, depicting differences between U13 and U14 players, with the older players exhibiting more stable behaviour.	11
*Coutinho et al. (2017)	Cross-sectional	Training	Youth players (n=12)	Soccer	Performance conditions, Spatial exploration index, Time synchronized in longitudinal and lateral directions, Length, Width, Speed of dispersion and contraction	Task (7v7) - mental fatigue - pitch reference lines	ANOVA Cohen's d	When the pitch lines were combined with mental fatigue the players positioning was affected, possibly due to the use of irrelevant cues.	13
Olthof et al. (2017)	Cross-sectional	Training	Youth players (n=148)	Soccer	Age group, SSGs formats, Game characteristics Physical and Tactical performance	Player - age group (U13, U15, U17) Task (5v5)	MANOVA Coefficients of variation	On a large pitch, physical performance significantly increased, inter-team and intra-team distances were significantly larger and tactical	13

						-field size (small, large)		variability of intra-team distance measures significantly increased.	
*Gonçalves et al. (2017b)	Cross-sectional	Training	Male players (n=19)	Soccer	Pitch area restrictions, Tactical behaviour, Physical performance, Physiological performance	Task (10v9) - field size (restricted, contiguous, free)	Cohen's d	The effects of limiting players' spatial exploration greatly impaired the coadaptation between teammates' positioning, while decreasing the physical and physiological performances.	12
Passos et al. (2017)	Cross-sectional	Training	Players (n=24)	Rugby	Players relative positions, inter-player angle, players velocity	Task (2v1) - type of instructions	UCM analysis	The strength of an interpersonal coordination synergy is supported by visual information, which means that adjustments in running line velocities were provided by players' relative position.	14
*Laakso et al. (2017)	Cross-sectional	Training	U16 Male players (n=15)	Football	Interpersonal patterns of coordination in 1vs.1 sub-phase, Variations in relative distance and Relative angle between the attacker and defender players to the centre of goal, Field locations	Task (1v1) - field locations (left, middle, right)	Cohen's d Pearson correlation	Relative position of the goal is a key informational variable that sustained participants' behaviours for dribbling and shooting	13
Prieto et al. (2017)	Cross-sectional	CPE	Male Official matches (n=12)	Basketball	Game period, Players and team synchronization	Environment - game period - competitive context	Relative phase ANOVA	The results revealed an increasing scoring coordination pattern between the teams as the games unfolded, showing extremely high coordinated behaviours in the 3rd and 4th quarters	14
Spencer et al. (2017)	Cross-sectional	CPE	U18 Male players (n=41)	Football	Intra and inter team coordination, Match duration	Environment - competitive context	Relative phase	Movement coordination was higher amongst midfield players within the same team and direct opponents between teams. Perhaps due to fatigue, interpersonal movement coordination decreased throughout matches	12
*Tan (2017)	Cross-sectional	Training	Male and female (n=8)	Modified throw and catch game	Rules manipulation, Ball possession Team synchrony	Task (4v4) - rules (herding, non-herding)	ANOVA Pearson correlation	Manipulation of task constraints revealed higher levels of clustering tendencies in the herding condition	14
*Baptista et al. (2018)	Cross-sectional	Training	Male players (n=23)	Football	Total distance covered, Distance covered while walking, jogging, running, and sprinting, Centroid distances, Individual area,	Task (7v7) - playing formations (4:3:0, 4:1:2, 0:4:3)	Cohen's d	Different playing formations supported different game dynamics, and variations on external load were directly linked with the variations on tactical behaviour	10

					Team length and width, Surface area, Playing formations				
*Bueno et al. (2018)	Cross-sectional	Training	Players (n=301)	Futsal	Spread, Surface area, Centroid distances, Age categories, Shots to goal, Interceptions, Offensive and defensive situations	Player - age group (U15, U18, professional)	Cohen's d	Players of younger categories played more compactly compared to the professional category. Different organizations on the court can determine the success in shots to goal or interception actions in each category	13
*Folgado et al. (2018a)	Cross-sectional	CPE	Male players (n=77)	Football	Intra and inter team synchronization, Match status, Final outcome	Environment - competitive context - match status	Relative phase ANOVA Cohen's d	Team movement synchronization's decrease in losing situations. Defensive dyads revealed higher synchronization values, than offensive dyads	13
*Folgado et al. (2018b)	Cross-sectional	Training	Players (n=30)	Football	Field position, Professional experience, Players' movement synchronization's Physical and Physiological indicators	Players - field position - level of expertise	ANOVA	Players' tactical performance seemed to influence their physical and physiological response. Higher levels of synchronization were correspondent to similar or lower levels of distance covered and heart rate responses	12
*Gonçalves et al. (2018a)	Longitudina l	CPE	Male players (n=28)	Football	Total distance covered, Frequency of near-in-phase synchronization, Intensity zones	Environment - key moments of play - competitive context	Cohen's d	Players experience mental fatigue when they are exposed to highly variable contextual situations with consequences on their physical and tactical performances (synchronization)	13
*Gonçalves et al. (2018b)	Cross-sectional	Training	Players (n=20)	Soccer	Effective playing space, Coefficient of variation, Players mean speed, Players number	Task - numerical relation (3, 4, 5, 6, 7, 8, 9, 10)	Cohen's d	The increase in the number of players influenced both regularity and absolute effective playing space areas	13
Travassos et al. (2018)	Cross-sectional	Training	Male Players (n=40)	Futsal	Team centre, Distance from each player to the team centre and the ball, Distance between each team centre and the ball, Number of targets, Age group	Task (5v5) - number of goal targets Player - age group (U9, U11, U15, U17)	Cohen's d	The use of only one goal target afforded an increase in the behaviour irregularity. The use of two goal targets boosted the team dispersion (mainly at U9 group), as well as higher behavioural regularity that contrasts defensive and offensive behaviours	12

Menuchi et al. (2018)	Cross-sectional	Training	Male Players (n=20)	Soccer	Interpersonal distance to the receiver, Interpersonal marker-receptor distance, Pass angle, Average pass velocity	Task (4v4) - rules (time and space) Player - age group (U13, U15, U17, U20)	ANOVA	Markers and passers are tightly coupled. The marker-passer coupling emerges from a flexible and adaptive exchange of passes, and is stronger in higher intensity, and older age groups	15
Alexander et al. (2019)	Cross-sectional	CPE	Male Players (n=22)	Football	Team centroid (x and y-axis), Team surface area, Team Length, Team width, Variability of Players Movement	Environment - match phase (offensive, defensive, contested) - Field position	MANOVA	Field position had a greater influence on the x-axis centroid. Match phase had a greater influence on length, width, and surface area. Players' movement were more variable during offence and defence match phases.	13
Browne et al. (2019)	Longitudinal	CPE	Male Players (n = 29,153 kicks)	Football	Performance outcome, Key task constraints	Environment - source, pressure, kick distance, possession time, velocity, target Players - level of expertise	Rule Induction Approach	Understanding of key constraints interactions, and prevalence during competitive performance, can be used to inform representative learning designs in athlete training programmes.	15
Chung et al. (2019)	Cross-sectional	Training	Male Players (n=20)	Football	Team's width and length, Match phase (offensive and defensive), SSG format	Task - Players' number (3v3, 4v4, 5v5)	ANOVA	The playing phase had a significant effect on width and length. During offensive phase, teams' width and length were significantly higher than during the defensive phase. e length was significantly lower on 3v3 compared to 4v4 and 5v5.	12
Connor et al. (2019)	Longitudinal	CPE	Players (n=43)	Cricket	Type of ball, Batting performance	Environment - type of ball	ANOVA	Pace bowlers were more successful transferring ball, while spin bowlers were more successful with the KB™ ball. Batters were able to adapt their movement technique and transfer their skill to the Duke™ ball conditions.	13
*Gonçalves et al. (2019)	Cross-sectional	CPE	Official matches (n=3)	Football	Effective playing space, Game width, Game length, Ball positioning, Offensive space available, Position of the deepest players' location	Environment - competitive context - opposition level	Factorial Analysis	The quality of opponents promotes a great variation in team behaviour as function of possession and is presented as an important factor to be considered.	14

Ireland et al. (2019)	Longitudinal	Training and CPE	Players (n=33)	Football	Game scenarios (training vs competition), Temporal, Distance, Pressure, Situational factors	Task - game scenario training drills (midfield, general play, stoppage)	Wilcoxon	It is likely that for training to more closely resemble games, ball-disposals (especially kicking) must be produced under highly contested conditions and executed within minimal time	16
Machado et al. (2019)	Cross-sectional	Training	Male players (n=48)	Football	Age categories, Tactical skill level, Team performance, Player exploratory behaviour	Task - Level of difficulty at SSGC	Mann-Whitney test	Team performance and players' exploratory behaviour were influenced both by the age and tactical skill level of the players, as well as by task difficulty level	16
McCosker et al. (2019)	Longitudinal	CPE	Male and Female (n=244)	Long Jumping	Competitive Performance (key constraints identification)	Environment - competitive context	Binary logistic regression	The key constraints shaping behaviours in long jumping relates to individuals (e.g. athletes' performance goals); performance environments (e.g. strength and direction of wind) and tasks (e.g. requirement for front foot to be behind foul line at take-off board).	14
*Memmert et al. (2019)	Cross-sectional	Training	Male players (n=62)	Football	Tactical formations, Effective playing space, Player length per width ratio, Space control gain, Pressure passing efficiency	Task - tactical formations	Wilcoxon	Practice task designs which manipulate team formations therefore significantly influence the emergent behavioural dynamics and need to be considered when planning and monitoring performance.	14
Pizarro et al. (2019)	Cross-sectional	Training	Male players (n=8)	Futsal	Decision-making, Execution of players' behaviour	Task - rules	MANOVA	The SSCG based on the manipulation of the games principles promotes adaptive behaviours similar to competition. Players improved decision-making and pass execution in the keeping the ball possession and progression to the goal principles.	14
Práxedes et al. (2019)	Cross-sectional	Training	Players (n=19)	Football	Decision-making Performance behaviours	Task - rules - SSCG (5v5, 3v3 +2, 4v3, 4v4 +2)	Wilcoxon	The NLP intervention programme was effective in improving both aspects of team games performance in youth players, with effects consolidated over time.	14
*Ribeiro et al. (2019)	Cross-sectional	Training	Male players (n=14)	Football	Number, size and location of goals, Game conditions, Ball possession, Field direction	Task - rules - players number (6v6	ANOVA	Large synergistic relations and more stable patterns were observed in the longitudinal direction for both teams, and for both game phases in 6v6 + 4 goals condition. Higher	13

						+ 4 goals, 6v6 + GK)		synchronies and more stable patterns in the lateral direction were found for both teams, and for both game phases in 6v6 + GK.	
Robertson et al. (2019)	Longitudinal	CPE	Male Players (n=9005)	Football	High frequency of kicking, Representativeness of key competitive events	Environment - source, pressure, kick distance, possession time, velocity, target	Rule Induction Approach	The rule induction approach provides a method capable of reducing the complexity of large datasets without compromising its inherent structure.	13
Silva et al. (2019)	Cross-sectional	Training	Male and Female Swimmers (n=18)	Swimming	Behavioural flexibility, Swimming speed, Stroke frequency	Task - swimming speed - stroke frequency	Cluster-phase	The variability on coordination might play an important role during training because it can reflect adaptive flexibility to task constraints. However, coordination variability did not always correspond to functional adaptation.	13
Timmerman et al. (2019)	Cross-sectional	Training	Players (n=13)	Field Hockey	Game format, Match performance, Physical demands, Players' number	Task -type of game (normal, cage hockey, possession, two-goals) -players number (6v6, 3v3)	ANOVA	Lowering the number of players will lead to more technical actions and a more physically demanding. Manipulating specific field characteristics will force players to focus on different perceptual information, which influences the technical skill, decision making and physical game demands	16

*Legend: *Studies also included on meta-analysis; CPE – competitive performance environment; SSCG – Small sided and conditioned games*

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Chapter III: Empirical Articles

Empirical Study 1

Developing players' tactical knowledge using combined Constraints-led and Step-Game Approaches – A longitudinal action-research study

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Abstract

Purpose: Using an action-research design, this study examined the impact of combining concepts from two contemporary pedagogical approaches, the Constraints-led Approach (CLA) and Step-Game Approach (SGA), on the development of youth volleyballers' tactical knowledge, as expressed in performance, throughout a full competitive season. ***Method:*** Fifteen players and one coach participated in this study, which involved three action-research cycles, each including the processes of planning, acting and monitoring, reflecting, and fact-finding. The first author, who had the role of coach-researcher, collected data using a reflexive diary and field notes between September 2017 and June 2018, as well as eight semi-structured focus-group interviews. Data were analysed using thematic analysis, in which inductive procedures deepened understanding of the development of the participants' tactical knowledge. ***Results:*** Findings suggested that combining CLA with SGA improved tactical knowledge in specific ways. Players progressed from a starting point where they were only able to describe game scenarios, and act without tactical criteria or considering contextual game constraints, to a point where their intentions during tactical actions were shaped by their ability to think strategically and guide their attention to recognize and interpret different constraints. ***Conclusions:*** Results suggested that the development of players' tactical knowledge benefited from a mutual integration of different, yet complementary, pedagogical approaches. By integrating SGA and CLA it was possible to enhance players' adaptable thinking using learning tasks involving the manipulation of meaningful constraints that afforded variable repetition and the resolution of tactical problems.

Keywords: player development; sports pedagogy; qualitative analysis; volleyball

In recent decades, research has suggested that team sports can be conceived as a dynamical system (e.g., Davids, Araújo, & Shuttleworth, 2005) comprised of a set of interdependent elements (i.e. cooperating and competing players) that self-organize and self-regulate to satisfy competitive performance constraints over time. From this perspective, the players can be viewed as being informationally coupled to the dynamic performance environment. As such, the outcomes of competing and cooperating players' coupled actions cannot be completely predicted in advance because they are dependent on dynamic environmental conditions which, in turns, continuously emerge and change as a consequence of players' actions at each game moment. This perspective is aligned with insights of researchers who have highlighted the importance of developing tactical knowledge (TK) for game-problem resolution (McPherson, 2008). Specifically, TK refers to the decision-making process and choices made related to the organization of functional tactical behaviours when performers interact with specific dynamically changing circumstances of unpredictable performance contexts (McPherson & Thomas, 1989). Indeed, the relationship between tactical needs and movement (re)organization is such that knowing (tactical skill) facilitates perceiving and doing (movement (re)organization and adaptations to changing performance conditions) and vice-versa.

The constraints-led approach to coaching and teaching emphasizes how, through task constraint manipulations, athletes can gain a profound adaptive relationship (i.e., development of a specialized comprehension underpinning tactical configurations of play under the effects of different, interacting environmental constraints (Davids & Araújo, 2010)). This type of 'knowledge of' a performance environment facilitates a deeply entwined and integrated relationship between knowledge, perception, and action to support learning and performance in sport (Araújo, Hristovski, Seifert, Carvalho, & Davids, 2019). In ecological psychology, a performer's contact with a performance environment is based on knowledge of the environment, which is deeply integrated with processes of perception and action that support decision-making. Gibson (1966) advocated a functionalist approach by arguing that knowledge about the environment involves perception - mediated by language, symbols, pictures, and instructions - that can all help analogical reasoning, problem solving, decision-making, and cognitive processes to verbally describe what an information source means. In contrast, knowledge of the environment involves perceiving the layout of the performance environment as it relates to an individual’s body and action capabilities (Turvey & Shaw, 1999). According to Gibson (1966), knowledge of the environment leads to knowing how to (re)organize actions because it involves the perception of information used to regulate actions needed to utilize affordances (i.e., opportunities to act) (Gibson, 1979). Knowledge of the environment involves acquiring perceptual information to directly constrain functional behaviours, such as perceiving the flight of a ball in space and the movements of an opponent in preparing an action. The development of players’ knowledge of the environment can be achieved by practice under meaningful and representative learning designs.

Thus, through exploratory behaviours, during practice and performance, the perceptual systems of a performer become progressively more "attuned" to the invariant information in the performance environment through direct experience in specific contexts (Silva, Garganta, Araújo, Davids, & Aguiar, 2013). Information picked up by a performer becomes more subtle, elaborate, and precise with task-specific experience and when it is coupled successfully to actions. The key point is that, although performers can learn knowledge about a performance environment, which can allow them to describe the decisions and actions they may undertake, coaches need to ensure that during representative tasks learners are using knowledge of the environment to (self)regulate using tactical behaviours and decisions to support the perception of information and continuously (re)organize actions (Araújo, Davids, & McGivern, 2018).

Previous research on TK has consistently supported the idea that players with a higher quality of TK are more able to perceive relevant surrounding information for action, reducing the time needed to interact with a performance environment (Kolman, Kramer, Elferink-Gemser, Huijgen, & Visscher, 2019). Indeed, they are better able to act during performance to perceive information to regulate further actions. Because the game rules in volleyball forbid players to carry (hold) the ball, fast play is encouraged (Mesquita & César, 2007). Therefore, the speed with which players interpret and respond to the dynamically changing informational constraints of the performance environment is vital.

Despite these important insights, few investigations have focused on development of TK in volleyballers, with much of that assessing the impact of different pedagogical approaches. In recent years, several emerging, second-generation pedagogical models (e.g. Teaching Games for Understanding, among others) (Ennis, 2014) have gained support. Conceived as player-centred practices, these contemporary models provide an applied basis for the development of skilful and tactically astute players who are engaged in actively building their own learning programs. The idea to place players at the centre of the learning process emerged simultaneously from constructivist and ecological learning principles. Such principles state that players develop their own performance understanding through the connection between their prior experience and knowledge that mediates their perception-action coupling in representative learning contexts (Mahoney, 2002; Mckay & O'Connor, 2018). The acquisition of TK from constructivist and ecological perspectives implies that performers enhance their deep tactical understanding (e.g., acquiring specific game-related 'knowledge of' a performance environment, in Gibsonian terms, to support perception and action) by engaging in practice designs shaped by the specific task constraints of each sport.

Given the specificity of tactics within team sports (particularly the differences between invasion and non-invasion games) the development of teaching models that recognize this specificity is needed. Following a constructivist viewpoint, the Step-Game Approach (SGA) was conceived according to the specific nature of non-invasion team sports (Mesquita, Graça, Gomes, & Cruz, 2005). Thus, conceptually the SGA is based on the tenets of Teaching Games for Understanding (TGfU). Its emphasis is on understanding the 'performance logic' imposed by a game, as well as appreciation of the tactical structure of play before the teaching of high structured techniques (Bunker & Thorpe, 1982). In addition, the SGA includes a didactical framework specific for non-invasive team sports based on the Skill Development Approach (Rink, French, & Tjeerdsma, 1996). The structuring of the teaching-learning process, through the definition of practice tasks (i.e., acquisition, structuring and adaptation) and strategies (e.g., questioning), according to different levels of learning, endows SGA with a didactical characteristic (Pereira, Graça, Blomqvist, & Mesquita, 2011). Thus, embedded in a player-centred perspective of teaching, the SGA advocates the specific development of performance abilities in non-invasive games (for instance, volleyball), in which players are presented with step-by-step game tactical problems during practice, which allows them to develop a functional coupling between tactical behaviours and movement skills (see Table 1 for further details) (Mesquita et al., 2005). Here, the question arises whether these practice designs are an important tool that guide the players towards self-reflection, self-regulation and adaptation, and problem-solving through posing open-ended questions in practice (Metzler, 2011).

Without disregarding the constructivist assumptions, but particularly highlighting the importance of ecological learning designs, a Constraints-led Approach (CLA) emphasizes a performer-environment centred approach focused on the mutual interaction between players and the task constraints of a specific performance environment (Chow, Davids, Button, Shuttleworth, & Araújo, 2007). This approach advocates the building of meaningful and representative learning contexts, through the manipulation of different constraints, that provide opportunities for players to act (i.e., affordances). Despite the importance of each approach, to date there have been no investigations about TK development using CLA and SGA pedagogical principles. Furthermore, there have been no studies that have explored the teaching-learning process when practitioners have attempted to use a combination of ecological representative design (in a CLA) with the provision of augmented informational constraints based on a constructivist and sport-specific didactic approach (SGA).

Therefore, research suggests that improvements in performance dimensions, including higher quality TK (based on 'knowledge of' a performance environment), is important for the development of experienced and skilled sport performers (Davids, Araújo, Seifert, & Orth, 2015). Despite the undeniable scientific contribution, the investigations have typically relied on quantitative assessments of the effects of learning interventions. In contrast, a qualitative analysis using an Action-Research (AR) design could offer a deep, contextualized, and continuous analysis and assessment of the teaching-learning process. Moreover, an AR-intervention could also promote an expansion of the comprehension about how the design of representative learning contexts (through manipulation of environmental and task constraints), might influence the development of players' TK. Moreover, an AR-design facilitates reflective monitoring and systematic manipulations of the task constraints in practice designs. There is an important emphasis in AR on the rich insights and experiences of athletes and practitioners during the practice process (Cooke & Wolfram Cox, 2005). Recently, an AR approach to assessing the work of practitioners has been applied in educational contexts such as physical education lessons (e.g. Farias, Hastie, & Mesquita, 2018), although the implementation of AR in sports training contexts remains scarce.

Purpose of the study

In the present paper we sought to explore whether a combination of constructivist (SGA) and ecological (CLA) approaches might serve as a useful framework for understanding how to improve the development of players' TK. Indeed, practice programs based on a manipulation of meaningful constraints that affords variable repetition and stimulates the ability to resolve tactical game-problems may help learners to enhance the adaptability of their thinking and tactical skills.

Accordingly, using an AR-design, this study examined the impact of combining CLA and SGA on the development of youth volleyballers' tactical knowledge ('knowledge of' a performance environment) throughout a competitive season. Through this interventive design we sought novel insights about the processes underlying TK development, rather than simply adopting an end-product perspective, that is, merely gaining information on differences between levels of TK in learners at the beginning of the season, compared to the end.

Method

Context and Participants

The study took place in a volleyball club located in the North of Portugal, which is one of the most prestigious in the male and female Portuguese National

Premier Volleyball Leagues. The club philosophy follows a long-term vision of developing young players for integration into senior teams. Purposive and convenience sampling criteria (Sarstedt, Bengart, Shaltoni, & Lehmann, 2018) were applied to select the fifteen female volleyballers who took part in the study. Players, aged between 14 and 15 years old, had experience of at least one year of specialized volleyball training and performance. Participants were chosen for the study because they were considered ‘information-rich’ once: (i) they were at the beginning of their development pathway, and (ii) of their ability and willingness to participate in the study. The first author assumed the dual role of coach-researcher. As a researcher, she completed a Masters’ course in Sports Training Sciences and a Masters’ degree in High Performance Sport. As a coach, she holds the highest level of coaching certification in Portugal (level III) and has accrued 6 years of competitive coaching experience with teams winning two national championships and one cup competition.

The study was conducted across the full length of a competitive season, which lasted from September 2017 to June 2018 and included two separate competitions: The Regional (September-January) and National championships (February-May). Both competitions were divided into two phases: the qualifying stage and the finals. A total of 143 training sessions and 32 official matches (18 and 14 matches from Regional and National championships, respectively) were completed during the research period. On average, each week, the players undertook four x two-hours training sessions and participated in one official competitive match.

The study followed the guidelines stated in the Declaration of Helsinki and was approved by the Institutional Research Ethics Committee of the first author’s institution. In addition, players and their parents were informed about the research scope, as well as the possibility to withdraw from the investigation at any time. After this, informed consent forms were signed by parents and players. Guarantees of confidentiality and anonymity were also explained, hence all names mentioned in the study are pseudonyms.

Study Design

The study followed an AR-design where the coach systematically and critically reflected about her own practice, and then changed it according to her own reflections (Bodner & MacIsaac, 1995). Specifically, an insider action-research paradigm was used, offering a privileged standpoint from inside the coaching process in competitive sport (Coghlan, 2007). Due to its reflexive, collaborative, and interventionist nature (Cooke & Wolfram Cox, 2005), the AR format offers the ability to monitor, control, assess, and adapt the coaching intervention designed to developed players' TK, whilst endorsing its reconstruction and transformation over a sustained and longitudinal competitive performance period.

A total of three AR-cycles were completed as Figure 1 depicts. Each cycle included the processes of planning, acting and monitoring, and reflection. As suggested by Gilbourne (1999), the first AR-cycle addressed context exploration by players. Additional diagnostic analyses were undertaken by the coach in order to identify the main tactical problems of the players and team, that needed to be resolved. Aligned with the study's purpose, the remaining two AR-cycles focused on combining the key principles of CLA and SGA to support development of the participants' TK. At the end of each AR-cycle, the reflections and identification of unresolved issues, in both training sessions and competitive performance, guided the re-framing of ongoing pedagogical practice. Considering the complexity of the coaching process and the inherent unpredictability of a competitive season, the ecological learning designs and coaching intervention were regularly adjusted depending on the daily challenges and problems faced by the coach.

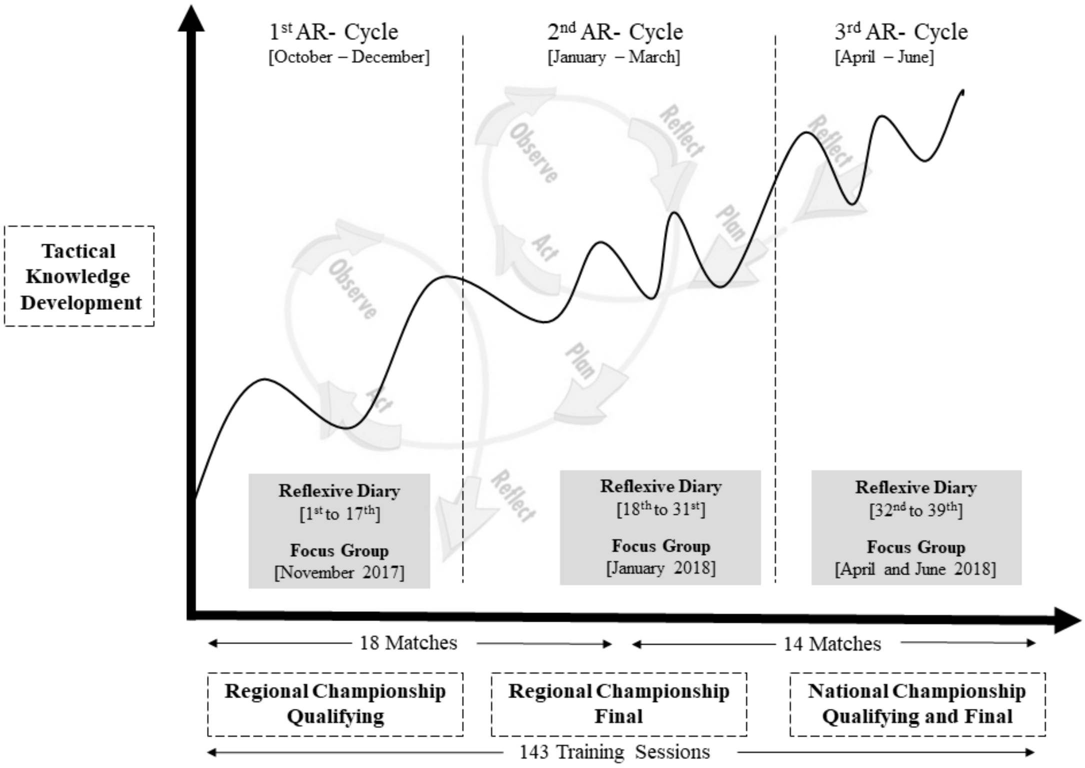


Figure 1. Action-research timeline

Coaching Protocol

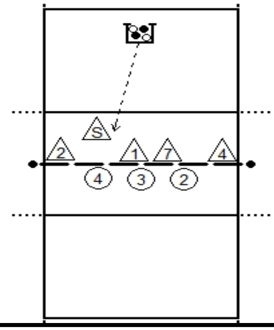
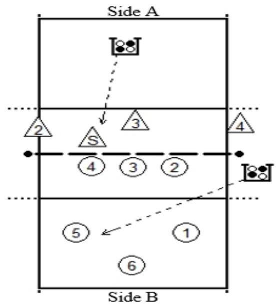
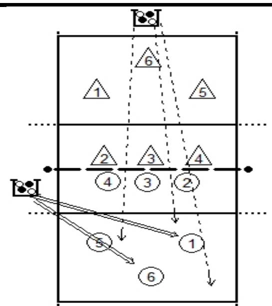
Each training session used an ecological representative learning design according to the principles of CLA (Chow, Davids, Shuttleworth & Araújo, 2020). The learning tasks followed principles relevant to tactical, instructional, and didactical constraints relevant to the specific demands of volleyball (i.e., SGA) (Mesquita et al., 2005). Table 1 provides a description of the main CLA and SGA instructional constraints manipulated. Additionally, an example of a training plan is presented in Table 2.

Table 1. Main instructional principles considered in each approach

Constraints-led Approach	Step-Game Approach
[1]***Manipulation of constraints*** - to shift the players intentionality, guide attentional focus, create a desirable instability, and encourage the problem-solving of a specific tactical/technical issue within multiple environments. [1]***Affordances driven designer*** – learning designs must develop players' understanding and allow them to construct for themselves the 'how, why, where, when' to perform an action. [1]***Co-adaptation*** – to achieve the task goal, players must cooperate with their teammates by self-organizing to satisfy the interacting constraints. [2]***Degeneracy*** – the task constraints offered both repetition and variation to induce adaptability in players' tactical/technical actions. [3]***Representativeness*** - practice task constraints represented the competitive performance environment so that players can maintain the same perceptual-motor relations with key events. [4]***Configurations of Play*** – the schema drawn from the relative spatial location of players according to the specific instructions received during training sessions. [1]***Complexity*** – the game-forms involved tactical problems of higher complexity, according to the currently tactical understanding of players.	[5]***Tactical Understanding*** – players must be invited to see the relationships among pieces of information to help them form connections between the tactical purpose of the game and the official game-form. [6]***Thinking strategically*** - the notion of strategy conveys a focused, intentional, relational, goal- and action-oriented sense of what the player does in the process of using declarative and procedural knowledge. [7]***Cue perception*** - players must be given opportunities to develop the experience of recognizing appropriate cues in a variety of contexts. [8]***Questioning*** – questions were generally related to a specific tactical aspect, and guided players to constructively build a solution, instead of merely prescribe it. Two types of questions were considered: (i) convergent questions, which require less knowledge and ability from players who are invited to provide a straightforward response; (ii) divergent questions, which entail multiple answers and, therefore, encompass a careful organization within a logical structure. [7]***Strategic plan*** – tactical principles of play, constructively discussed and defined before the game, which guided collective or individual tactical behaviors. [9]***Content didactical development*** – Three types of instruction were implemented: (i) acquisition, focused on the development of a specific skill, (ii) structuring, focused on understanding the tactical and technical skills of the game but without opposition, and (iii) adaptation, in which in which the goal, action structure, and basic tactical features were identical to the full volleyball game. The adaptation tasks included thematic games (i.e., conditional game-forms), where the specific action structures were emphasized without overlooking adherence to the main game goal (e.g., giving extra points to attack or blocks actions), and small sided and conditioned games in which specific tactical issues were emphasized. Accountability criteria were frequently added to each one of these tasks to assign players responsibility for their own learning.

Note: the instructional principles presented were conceptually adapted from: [1]Roberts, Newcombe, and Davids (2019); [2]Seifert, Komar, Araújo, and Davids (2016); [3]Headrick, Renshaw, Davids, Pinder, and Araújo (2015); [4]Gréhaigne and Godbout (2014); [5]McPherson (2008) [6]Mesquita and Graça (2002) [7]Buekers, Montagne, and Ibáñez-Gijón (2019) [8]Metzler (2011) [9]Mesquita et al. (2005)

Table 2. Example of a training session plan belonging to the 2nd AR-cycle

	Explanation			Graphic
	General	**Questioning examples**	**Task constraints**	
Type of task: **Acquisition** Objective: **Block**	Players must achieve double block on zone 4, zone 3 and zone 2. Three sequences from two different attack zones were created as follows: Sequence1: Middle (1) + Zone 4 Sequence 2: Middle (7) + Zone 2 Sequence 3: The setter chooses the first ball to the middle (calling play 1 or 7) and the second attack is from zone 4 or zone 2, respectively.	-Where are you looking? To the ball or to the setter? Why? -When should you delay your jump? Why? The previous attack was slow or fast? -From where was the attacker's shoulder directed? And your hands, were between her shoulder?	-The last sequence is defined by the setter -The attacker on the boxes can chooses to toss the ball low or high -The players' hands must be between the net and the rope fasten above the net -The players must block-line on zone 4 and zone 2	
Type of task: **Structuring** Objective: **Defense/defense relationship and attack on counterattack**	Players must conduct all actions regarding to transition-phase. The attack action is performed without opposition. One sequence of seven balls was created as follows: 1st FB tossed to Side A – only middle-blocker can attack 2nd DB attacked to Side B from zone 4 3rd FB tossed to Side A – only middle-blocker can attack 4th DB attacked to Side B from zone 2 5th FB tossed to Side A – only zone 4 or 2 can attack 6th DB attacked to Side B from zone 2 or zone 4 7th FB tossed to Side A – all attack options are available	- Did you think that you had a good angle to attack on that trajectory? - Why did you set to her? Did you feel comfortable to reverse the ball? - Where did you see the middle? What space are you covering?	-The last three balls are defined by the setter -The attack from Side B must be directed to the targets displayed in the court -The Side B must win the sequence to achieve de task goal	
Type of task: **Adaptation** Objective: **Counterattack organization**	Conditional game on 6x6 format. The rallies start according to the following sequence of five different balls given to the same side: 2x Downballs* 3x FreeBalls** The set stars at 15/15 until 25 points.	-Why did you set to her? Which were her opponents' blockers? -Look to the set score, who will attack the next ball? Why? Ok, so define the block priorities -Did you see the block open? Why did you attack there?	-The Setter's options during Freeballs are constrained as follows: 1st Middle-blocker or Zone 4 2nd Middle-blocker or Zone 2 3rd Free -Positive block contact or defense are rewarded with one extra point.	

*Note: *Downball - occurs when the blockers decide there is no need for blocking, but still the opponent is capable of producing an attack with a downward trajectory **Freeball - occurs when the opponents will predictably send an easy ball, not having the possibility attack;*

Instructional and treatment validity

In order to ensure that an integration of CLA and SGA was achieved, the coaching protocol was validated by one researcher of the present study, and an externally trained observer not associated with the study. The external observer had extensive research in pedagogical approaches and analysed the documented training plans and video records of training sessions. The few disagreements were discussed and resolved among the research team (first author and co-authors). A ten-item checklist was adapted from the studies of Práxedes, Álvarez, Moreno, Gil-Arias, and Davids (2019) and Pereira and colleagues (2011) to test the behavioural fidelity of the coaching intervention. Accordingly, 18 training sessions - more than 10% of the total sample - were randomly examined by both, the external observer and one of the co-authors for the presence of items included in Table 3 (Tabachnick & Fidell, 2007). Items 1, 2, 4, 5 and 6 are characteristics of SGA, while items 3, 7, 8, 9, and 10 are related to CLA. The external researcher and one of the co-authors, both pedagogical experts, confirmed that key, integral concepts of CLA and SGA methodology were used in each observed training session. A 100% agreement between these observers confirmed the absence of doubt regarding to the integration of both pedagogical approaches.

Table 3. Instructional checklist

Elements of the training session	Present	Absent
1. Creating a tactical problem as the organizing centre of learning tasks.		
2. The coach explains the task, observes individual and collective behaviours, and uses questioning to induce players' reflection.		
3. The tasks and game complexity increase throughout the season.		
4. All training sessions include task acquisition, structuration, and/or adaptation.		
5. The tasks frequently include accountability criteria.		
6. The training sessions closed with SSCG or thematic game stressing the application of technical and tactical skills initially addressed.		
7. Manipulation of constraints of the full game were performed.		
8. All tasks were constrained in terms of rules, space, and/or time.		
9. All tasks required the exploration of different performance solutions by the player.		
10. All tasks were built in order to ensure that learning designs represent the competitive performance environments.		

Data Collection

The study used multiple sources of evidence to gain an in-depth understanding of the coaching process from all participants' perspectives. The coach's perceptions were recorded by a written Reflexive Diary (RD) and Field Notes (FN). Players' insights were recorded during Focus Group sessions (FG). A total of 39 coach reflections and 8 semi-structured focus group interviews were conducted.

Reflexive Diary

The RD was written by the coach (first author) and contained information from a critical and emotional perspective about the events, providing evidence of context comprehension, self-awareness, and professional judgment (Thomas, Morgan, & Mesquita, 2013). A total of 39 coach reflections were collected. The RD's purposes were: (i) to think critically about the influence of the coaching intervention applied on development of players' TK, (ii) to inform the training process, (iii) to generate useful questions that guide focus group sessions, and (iv), to create new insights derived from data. The FN, collected during training sessions, guided the writing of the RD, and reflected the most critical observations, perceptions, personal experiences and events that occurred.

Focus-Group

A total of eight FG sessions were conducted. For each interview, the team was divided into two groups of seven and eight players respectively (Sparkes & Smith, 2014). Throughout the first and second AR-cycles, four FG sessions were conducted (two for each AR-cycle). The third AR-cycle included the remaining four sessions. The interviews took place during the training session, in a quiet location inside the volleyball club. Interviews lasted approximately 60 minutes. All FG sessions were audio recorded and transcribed verbatim by the first author. The purpose of FG interviews was to elicit players' perspectives about their TK development. Being semi-structured in nature, such interviews supported the players' reflections and evaluations about a specific framework (i.e., individual and team tactical behaviours during competitive environments and tactical purposes of the learning tasks conducted during the training sessions), offering the opportunity to gain deeper information about crucial issues. Accordingly, FG sessions enhanced data quality by encouraging interactions among participants which, in turn, allowed the researcher to differentiate consistent themes from extreme views (Patton, 2015).

Data Analysis

The data were analysed throughout each AR-cycle (see figure 1). A thematic analysis was used to analyse the data from RD and FG. Thematic analysis was chosen because it enabled the researcher to identify, analyse, and report patterns (themes) within the data set (Braun & Clarke, 2012). Based on the proposals of Charmaz (2014), the first stage of this process comprised a repeated reading of the data from RD and FG interviews followed by an inductive line-by-line open coding of the data to capture thoughts, ideas, and meaning as well as to search for patterns. The second stage of this processes involved analysing the defined codes and testing possible combinations that guided the construction of themes and subthemes (focused coding). Such process included an attempt to interpret potential relationships between codes and themes by adding a chronological perspective on the data. The next level of analysis included working back and forth between data and theory. Issues about coaching pedagogies, a tactical framework for players' tactical development in team sports (Mitchell, Oslin, & Griffin, 2013), and building ecological learning designs (Chow et al., 2007) were used to examine, clarify, and reflect sensitively about the data. Nevertheless, an explicit effort was made not to force data to fit the theory, but rather to search for patterns and comprehend how it might support or oppose current conceptualizations.

Trustworthiness

To enable a change to occur, an insider action-research design requires the researcher to strike a balance between closeness and distance (Coghlan, 2007). The first author tried to deal with the consequences of their presence by building trust and a caring environment, as well as showing impartiality during the process (McNiff, Lomax, & Whitehead, 2003). Three additional procedures were undertaken. First, data triangulation involved the cyclical and iterative collection of data from different sources (i.e., FN, RD and FG interviews). The frequent interpretations from the coaching intervention and team events were continuously validated through additional data generated throughout each AR-cycle (Denzin, 2012). Second, in order to verify the accuracy of the coach-researcher's interpretations, players were frequently asked about both the implicit meaning of their verbal reports and their tactical actions, not only about the implicit meanings of their actions, but also about their verbal interventions. Third, regular peer debriefings with the research team (first author and co-authors, who are currently volleyball coaches and/or experts in sport pedagogy research) were held to minimize individual research bias in the interpretational analysis (Patton, 2015).

Results

Data analysis generated three main themes representative of players' TK development: "tactical awareness", "emerging understanding", and "playing tactically". The ability of players to adapt tactically to the game context reveals tactical awareness. Emerging understanding captures the players' ability to establish a connection between the purpose of a constrained game-form and the formal competitive game-form, in other words, understanding the relationships between the informational constraints of each environment (practice and performance). Finally, playing tactically relates to the use of tactics during competitive performance. This implies the recognition of an opposition's strengths and weaknesses, as well as teammates' strengths and weaknesses.

1st AR-cycle [September 2017 - December 2017] – What is the baseline of players' TK?

Tactical Awareness

At the beginning of the season, players were able to verbally describe their *knowledge about* their opponents' tactical behaviours, knowing what (declarative knowledge) and how (procedural knowledge) they could perform an action.

However, they were not yet capable of verbally describing actual the tactical perceptions, decisions and actions undertaken (based on *knowledge of* opposition behaviours perceived and acted upon). The following excerpt supports this idea.

"At this point of game analysis, I think they can see what's going on, but cannot interpret it or build an appropriate strategy that is based on the opponents features, because when I asked where they thought that they should serve to, all the team agreed they should perform a diagonal service, but no one was able to explain to me why"

5th RD, 16th October

Moreover, players were capable of perceiving opposition placements (an environmental constraint), but were not able to identify critical information sources, and consequently anticipate opposition defensive moves, due to the inherent unpredictability of the competitive performance context. Accordingly, players frequently adopted an attempt-error strategy, revealing a preliminary ability to vary and adapt their offensive options.

"Rose: After some rallies we understood where we should have attacked.
Researcher (R): But did you change your attack trajectory for any reason?
Rose: Sometimes we have a purpose, others not… sometimes we just want to try new actions for instance, when we are not able to score through a line-attack, we try the diagonal-attack.

1st FG, 23rd November

Emerging Understanding

Initially, players were not able to identify or comprehend how the manipulation of tasks constraints could create representative opportunities for them to act (i.e., affordances), or guide their perceptual awareness of the relevant information offered by the context (e.g., providing 'knowledge of' the location of the smaller blocker). To allow players to develop adaptable skills within a representative tactical task setting, the coach consequently constrained practice tasks with the purpose of providing opportunities for varied actions or 'repetition without repetition' (Bernstein, 1967). During practice, the coach guided the players' attention to the most relevant informational constraints to make the practice more meaningful and to stimulate the players' understanding. The next excerpt emphasizes this process:

"I clearly explained why we were doing each task. For instance, in a structured task I explained that we were training the line-attack because we needed to attack against the smaller blocker […] Indeed, I feel that players' performances improved when they understood the purpose of the task"

5th RD, 16th October

Playing Tactically

The players' use of tactics in competitive performance environments was found to be simplistic and mostly associated with a pre-planned strategy. Indeed, players could not describe a focused and intended goal-oriented action. Moreover, the contextual constraints (e.g., emerging match status) seemed to inhibit variability in the setters' tactical choices, that is, the ability for the players to coordinate actions to take advantage of perceived opposition weaknesses. As the next excerpt depicts, at decisional set moments, the setters tended to set to their best attacker without considering contextual performance constraints such as who was in the opposition block, or which offensive combination could generate a greater advantage.

"R: In your opinion, which is the best zone to serve to? Why?
Elizabeth: Zone 1, because I serve with my right arm, so I have a larger area to serve
Kate: And the ball arises on the back of the opponent's setter
[…]
R: Kate, do you feel that your setting options changed since 20 points?
Kate: I cannot vary the game, I only set to the player who I know is going to score more."

1st FG, 23rd November

2nd AR-cycle [January 2018 – March 2018] – interpreting constraints to evolve TK

Tactical Awareness

The players perceived that increases in learning task complexity, via the introduction of different task constraints, stimulated their thinking and focus. In fact, practice in complex representative scenarios helped the players to become perceptually attuned to the emergence of important affordances. In turn, these perceptions led players to consider the purpose of their own tactical actions based on what they perceived to emerge during game play, and to not merely

rely on the coach's recommendations. The next excerpt supports this observation:

"R: You said that you are currently better able to understand the game. Is there any connection with the increase in game complexity?
Katherine: Yes because this forced us to think.
Kate: We are more focused now.
Katherine: Yes, once the game became more complex we needed to stay focused, think more and this ends up affecting us […] for instance, during the attack, now I can see the block but, in the past, I only did what the coach told to me, without think about it.

2nd FG, 20th January

Practice task designs also provided the players with opportunities to develop their ability to perceive critical information sources that constrained their technical and tactical actions to adapt to the dynamic performance context. Accordingly, in the first evidence of strategic thinking, the players revealed how they were becoming more aware of opposition play features and future possible moves. The comments of Katherine and Mariah below clearly support this idea. Additionally, as stated by Emily, questions related to specific tactical actions helped players to reflect on their performance and explore various solutions constructively.

Mariah: […] For instance, if I saw the block is open, I would attack between the blockers
Katherine: yes, likewise, if we saw the defense moves up, we would attack the back of the court
[…]
R: Emily, you said that currently you understand the game better… in what actions?
Emily: Now, I know who I should set to.
R: […] what do you think that helped you improve?
Emily: the coach, for example, you [coach] *asked me why I set to someone that failed 5 consecutive service-receptions."*

2nd FG, 20th January

Emerging Understanding

At this stage, players started to establish a connection between the purpose of a constrained practice task and the tactical demands of competitive volleyball. Manipulation of task constraints in practice seemed to; (i) guide the players' attentional focus, (ii) stimulate their understanding of different game scenarios and increase the repertoire of performance solutions available to them in offensive and defensive game sub-phases, and (iii), facilitate their problem-solving in the competitive performance environment. In this sense, as Katherine later expressed, the training sessions started to gain more practical meaning.

"R: What did you think helped you develop your understanding of the game?
Ellen: The coach planning a lot of specific tasks and through them, we can develop our mind
Emily: And complex tasks […] conditional game-forms
Katherine: Where we must be focused
[…]
R: Do you think that the training tasks have a connection to the formal game?
Penny: The best players usually attack to the same zones, and we practice this type of defense
Liz: Yes! And the block! There are also several block tasks based on the team features of our next opponent
R: Are these types of tasks important?
Lisa: Of course!
Loren: It is much more similar, it is identical [to the official game]
Liz: And it is much more specific, so then it's easier to solve problems during the game"

2nd FG, 20th January

"R: Do you think we play more game-forms?
Katherine: yes, and we do it at the end of the training session, meaning we can use what we had practiced before […] For instance, when we are training collective block organization, then during the game we can apply it. We train with a purpose"

3rd FG, 4th April

Use of convergent questioning, while supporting the players' awareness of team role responsibilities, also contributed to perception of opposition tactical features and weaknesses. This process helped inform players how to instigate a competitive strategy to exploit perceived opposition limitations.

"During a constrained game-form situation I stopped the game and asked one of the teams which are the opponents' spikers at that exact moment, and to who the setter will probably set…players started to talk between each other, defining block priorities…Then I said, this is the purpose of the task, Agatha, as a middle-blocker, you have the responsibility to lead the block organization, focus on it."

25th RD, 18th February

Throughout this process, where representative learning tasks were designed to promote players' intentionality and to stimulate inherent self-organizing tendencies within the team to satisfy the interacting performance constraints, the coach's learning support progressively decreased. Therefore, by developing tactical knowledge, players began to understand some reasons for their errors, and how to change their performance to resolve emerging issues.

The players' reflections on their tactical options became essential to inducing their skill adaptation. Emily's example here supports this observation:

"When we were training final set moments, that is, a game phase that highlights tactical awareness, Emily failed three consecutive setting options, and I just screamed EMILY!!! She came to me and said that she knew that she should not have set the ball to Jennifer. I asked her why, and she responded that as she had good setting conditions and had Mariah and Kate in attack positions, she should set to one of them."

27th RD, 4th March

Playing Tactically

Because of the players' initial difficulties in identifying opposition weaknesses and tactical application during competitive performance, while considering the contextual performance constraints, the coach increased the use of divergent questioning during training. The main aim was to allow players to make sense and apply meaning to the information that they perceived, as well as induce links between new information, their previous knowledge and experiences. Players were also encouraged to explore different technical skills and to develop diverse tactical performance solutions. The next excerpt clarifies this process:

"Kate, why did you plan that move with the middle blocker? Why did you set to her? […] Or Mariah, who is blocking you? What do you think you can do to score? […] and it was enjoyable because they were answering me, executing different actions, and improving their game understanding"

28th RD, 11th of March

Additionally, before each competitive match, the coach initiated some discussions on tactical configurations of play (i.e., how players should act individually and collectively, in terms of spatial location) with players to simulate their strategic thinking. Such configurations emerging from these discussions were defined according to the shared understanding of the coach and players, as well as specific opponents' performance features. Subsequent training tasks were constrained by these tactical principles, meaning that players had the opportunity to stabilize perceptual-action couplings aligned with the key events of a competitive context. As a result, players started to act intentionally, understanding how exploit perceived opposition weaknesses.

"R: What do you think about when we build a game plan?
Rose: In almost all matches this help us, because during the game we know exactly what the weaknesses of the opponent are and where we should attack
Katherine: Now, we did not feel so lost on the court because we had an idea of what they can do
Kate: And we know what we need to do to score
Lilian: For instance, we attack according to the opponents' defensive organization, if they defend using another form, we certainly execute different type of attacks
Kate: and sometimes we cannot remember what the coach told us to do, and so we see the videos again and figure out what we are supposed to do"

3rd FG, 4th April

3rd AR-cycle [April 2018 – June 2018] – achieving a sustainable and adaptable TK

Tactical Awareness

By now, players had developed a reasonable technical ability and were able to perceive critical information sources to regulate their actions during performance. Given the crucial role of setters during the game, the coach decided to move a step forward in terms of tactical setting issues. Consequently, a strategic plan specific to setters was discussed between the coach and setters. Setters were invited to identify and interpret the contextual constraints of opposition defenses, as well as to develop a plan to counter such features. Through this process they enhanced their strategic thinking. The next excerpt clarifies this process:

"I made setters come early to training sessions as I wanted to discuss a setting plan with them, for the first time […] I explained everything, in which cases we should play with overlap or reversal, when we would play with middle-blockers […] during the formal conditioned game the correct setter option was often achieved, with rallies being conducted with a setter's criteria"

33rd RD, 15th April

This training process led to a progressive increase in the intentionality underpinning the tactical awareness of setting actions at each moment during performance. Moreover, constraints introduced in thematic training games created a desirable instability (known as 'metastability' in dynamical systems theory: instability that promotes different options for a complex system). These practice designs encouraged problem-solving within unpredictable learning environments. Consequently, representative affordances emerged from practice task designs which, supported by the coaching intervention, was extremely helpful for the players' tactical development. This was noted by Emily.

"R: How do you think the game evolved across the season?
Kate: I think we started to understand the game moments better. For example, at 24/24 we will set to a player that is displaying higher consistency across the game.
Emily: Yes, at the beginning I only set to Mariah, now I vary the game, for example, if she fails, I know that I cannot set to her again, immediately […] I always look for the opponent blockers', for instance, if Liz is in zone 2, I play a stick with middle-blocker
R: And do you think that the conditional game-forms helped you?
Emily: Yes […] and… sometimes I set to the best attacker, but the coach told me she is attacking against the best blocker and let me think about it […] the coach also helped me […] and I started to understand. At the beginning I set without looking at the blockers"

4th FG, 2nd June

At the end of the season, some players also started to reveal their capacity to anticipate emergent, competitive game scenarios. In this sense, players began to act according to the predictions of their own action outcomes. However, such enhancements in tactical awareness and anticipation of events were mostly emphasized for attacking and defensive actions.

"Mariah: It depends because I can attack against block or not. I know that block will probably close the cross-attack once is my best spike trajectory, therefore I to try the line-attack.
Agatha: During the last game, when I was performing the service, I was trying to serve to zone 1 with the purpose of increasing the odds of zone 2 attacks. I'm not able to dig [she digs in zone 5] *and I knew that zone 2 only executes cross-attacks, so as I'm digging the line-spike, I thought it could be a good strategy […]"*

4th FG, 2nd June

Emerging Understanding

As players improved at satisfying tasks constraints during practice, the thematic games became more specifically constrained by considering key tactical features of specific opponents. In addition, players were praised for their performance of technical or tactical actions required of these specific performance constraints. These specifying learning designs motivated players and encouraged their cooperation and self-organization to achieve specific performance goals.

"The training plan was centred on a formal conditional game, constrained according to features of the next opponent […] this is the most representative and specific task that I could do. Specifically, I introduced many freeballs [i.e., an easy ball played by opponents when they have no attacking options*] which only zone 4 and 2 could attack because our next opponent rarely uses the middle-blocker attack"*

36th RD, 5th May

"R: Do you think that what we practice during the initial part of the training session is also related?
Kate: Yes, because if we trained block and defense, these technical actions give us extra points during the game-form
Penny: For instance, when we train the block action, during the game-form a positive block action is rewarded with an extra point

4th FG, 2nd June

Such interventions allowed players to perceive and understand performance constraints and attend to critical information sources (e.g. attention on orientation of an opponents' arm and hand, and not only on the ball). This learning design helped players to anticipate opposition moves and adapt accordingly.

"R: […] reading the game… what do you mean?
Katherine: For instance, when someone is attacking, and we are defensing… now we look to their arm and we anticipate the attack trajectory
R: Did you think about it initially?
Katherine: I did not look so much, and if I looked, I couldn't understand it. Now, we also see the block and the setter, the setter cannot trick me anymore.
Mariah: Yes, when I'm attacking, I can see the block and, as a result, I know where I should hit […]
R: And at the beginning, what did you look for?
Rose: ball
Agatha: I only stayed in my defense zone
Rose: We were just worried about the purpose, that is, to defend
Liz: Yes, we did not think to look at the hitter's arm"

4th FG, 2nd June

Playing Tactically

Gradually, the process of recognizing and tactically exploring opposition weaknesses became more efficient, although this applied mostly to service actions. Here, enhanced understanding of tactical configurations of play, discussed with players throughout the season, played a critical role. Overall, by the end of the season, the players' performance actions clearly showed how they considered ecological constraints underpinning competitive performance. This is highlighted in the next excerpt:

R: Do you remember how we exploited that weakness?
Kate: Through a consistent service and serving on the other side of the team's best attacker.
R: When you are on the service line, do you think about it?
Emily: Sometimes
Mariah: It depends on the game moment
R: And was it always like that?
Group: NO!!!!
R: So, what happened at the beginning of the season?
Agatha: Initially, we only executed
Lisa: We couldn't serve to a specific zone
[…]
R: Do you think that game plans helped you to increase your game understanding?
Group: Yes!
R: But what does that mean?
Ellen: To understand the opponents' weak features and to know how to exploit it."

4th FG, 2nd June

Discussion

Using a three-cycle action-research design, this study examined the impact of combining methodologies from the CLA and SGA on the development of tactical knowledge of performance in youth volleyballers throughout a competitive season. Overall, combining both approaches, results showed how players progressed from an initial start point where they were able to verbally describe game scenarios to an end point where they had begun to think strategically. In fact, initially players relied on knowledge about how to perform (declarative and procedural knowledge, respectively) without considering tactical game constraints. After the intervention, however, they were able to act intentionally, narrow their attentional focus to perceive different informational constraints, and understand and share affordances to act tactically. By using an AR-design, it was possible to closely monitor the entire dynamical coaching process involved in participants' TK development. Indeed, the immersion of the coach-researcher in the context of youth volleyball training allowed for daily adjustments to the design of the ecological practice tasks, based on the tactical needs of the players and team.

The first AR-cycle diagnosed the players' tactical limitations (essentially based on their lack of tactical awareness). At this initial stage, players displayed the ability to verbally describe scenarios (knowledge about the performance environment) but were not capable to actively identify critical constraints during play. Instead, they merely reacted to affordances (opportunities for action during competition) rather than utilizing, sharing, or even anticipating them. These findings suggest it was difficult for players to use tactics in competitive environments because they were not aware of interacting constraints (e.g. opponents' weaknesses) and could not focus their attention on key information sources.

To resolve this issue, during the second AR-cycle the complexity of volleyball practice settings was increased via the manipulation of representative task constraints. Here, the purpose was to introduce a desirable instability that encouraged players' problem-solving and intentionality in their actions. During these learning tasks, tactical solutions were built, and assessed constructively, using questioning strategies. Combining ecological and constructivist perspectives, it was interesting to find that the increase in complexity of representative learning tasks was accompanied by a growth in players' awareness of their own TK development. Globally, during the second AR-cycle, the players affirmed that the greater task complexity improved their attentional focus, tactical understanding, and strategic thinking. This finding aligns with recent work by Shaw et al. (2018) that showed how increases in task demands led to increased mental engagement and consumption of attentional resources. Nonetheless, two possible reasons could also explain the players' perceptions. First, the convergent and divergent questions asked during practice might have invited participants to recognize and think about relationships among sources of information, activating their prior knowledge and helping them to establish connections between the tactical purpose of the task and the competitive game-environment. Second, representative task constraints might have guided participants' attentional focus, thus facilitating the perception and utilization of shared affordances.

Also, within the 2nd AR-cycle, the spatial locations on court that players should occupy, individually and collectively (i.e., configurations of play), started to be discussed constructively between the coach and players (Gréhaigne & Godbout, 2014). Such discussions were aimed at reducing the difficulties portrayed in perceiving opponent weaknesses. A strategic plan was then built during the study of opposition performance characteristics through video analysis. Afterwards, practice tasks were designed according to emerging tactical principles. This coaching intervention enabled players to redefine their understanding of the link between performance constraints and appropriate tactical skills, and thus increased action-oriented and adaptive gameplay skills (Araújo et al., 2019; Mitchell et al., 2013).

At the end of third AR-cycle, players showed a substantial improvement in TK. For example, in the first AR-cycle, Kate's record revealed that her tactical setting decisions did not consider contextual constraints (e.g., final set moments). However, by the end of the season, Kate was able to consider the match status, the performance of her teammates, and the performance features of immediate opponents during the game. Emily's report also showed a significant development in setting using tactical criteria. Overall, she emphasized the crucial role of strategic planning and the manipulation of representative constraints during thematic games. Indeed, as Gréhaigne, Caty, and Godbout (2010) postulated, the process of studying predominant configurations of tactical problems seemed to sustain the players' capacity to identify emerging regularities in opposition patterns of play, facilitating an anticipation process.

As a result of the strategic plan and manipulation of representative task constraints, by the third phase, players had increased their perception and understanding of informational constraints of performance (e.g. especially weaknesses of individual opponents). Consequently, they collaborated and self-organized with teammates to intentionally exploit such perceived vulnerabilities. Players had improved their anticipation of opponents' moves, implying tactical knowledge development. These anticipatory capacities were mostly observed in spike and dig actions, possibly because these tactical actions were directly related to opposition tactical moves. Anticipatory responses have greater tactical value in team sports where players are constantly required to make rapid, accurate decisions in a dynamic performance environment play (Gorman, Abernethy, & Farrow, 2018). Here, the building of representative learning designs played an important role in simulating task constraints that enabled performers to act adaptively, as required in competitive performance environments.

In practical terms, our findings recommend that coaches constrain their learning tasks designs according to: (i) the individual needs of players and the team , (ii) the specificities of the sport, and (iii), the tactical problems that need resolution, identified by performance analytics. Coaches should focus on building representative learning designs in practice. Finally, we endorse the combined use of convergent and divergent questions during the practice training session rather than simply prescribing tactical solutions for the players. Due to the complex relationship between perception, cognition and action underlying tactical knowledge development in youth players, we recommend the integration of different yet complementary pedagogical approaches in future investigations. This recommendation is aligned with our main findings revealing the development of players' tactical knowledge e through the combination of SGA and CLA approaches. The data highlighted that continuous exposure to ecological and meaningful contexts helps players develop a deeper knowledge of a performance environment for constructing novel performance understanding to adapt and evolve tactically.

What does this article add?

This article presents novel, qualitative longitudinal information about the impact of combining two distinct pedagogical approaches in practice designs. The combination of two different approaches that have traditionally been studied in parallel (i.e. the integration of ecological and constructivist ideas), represents a potentially useful way to enhance the cognition, perception and action of developing athletes. This study emphasizes the potential to integrate these approaches in order to address the complexity of practice demands and the individual needs of players and teams. Moreover, the innovative use of an action-research design during training sessions offered a deep, contextualized analysis of the coaching process throughout a competitive season. There was a specific focus on the continuous process of TK development, rather than just on the end-product (i.e., comparing how players started and ended a season in terms of TK).

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Empirical Study 2

Increasing tactical complexity to enhance the synchronisation of collective behaviours: An action-research study throughout a competitive volleyball season

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Abstract

An Action-Research (AR) design was implemented throughout a competitive season in which Constraint-led and Step-Game approaches were combined. This intervention study investigated the impact of increased performance complexity on emergence of counterattacking synchronisation tendencies in team players (laterally and longitudinally on court) at different set moments. Fifteen youth volleyball team players were studied across three action-research cycles, with performance in one competitive match analysed per cycle. Team synchronisation tendencies were assessed using the cluster phase method, with a 3 (matches) x 2 (set moments) x 2 (court direction) repeated-measures ANOVA statistical procedure to calculate differences in cluster amplitude mean values. Results revealed a reduction in team synchrony levels when tactical complexity of counterattacking play increased (second AR-cycle). Nevertheless, similar levels of team synchrony emerged between the first and third AR-cycles. Results also revealed the final moments of a set as a significant environmental constraint that shaped synchronisation tendencies. Evidence suggested that the (re)achievement of functional synchrony was realised through integration of Constraint-led and Step-Game approaches during practices designed to enhance tactical awareness in players. Finally, an insider action-research design provided relevant contextualised insights on the development of a team's synchronisation tendencies.

Keywords: constraint-led approach, step-game approach, player development, sport pedagogy, volleyball

Introduction

Over the last decade, researchers have argued that team sports performance analysis should focus on behavioural interactions emerging between teammates, so that competitive performance can be explained rather than merely described (e.g., Passos, Araújo, & Davids, 2016). An ecological dynamics conceptualization has been used to clarify how players' actions self-organize to systematically form new functional and coordinative structures, by exploiting inherent tendencies for synergy formation in teams (Woods, McKeown, Shuttleworth, Davids, & Robertson, 2019). Indeed, considering that a team functions as dynamic system, it is important for researchers to study how system elements mutually cooperate to satisfy the interacting constraints while achieving intended task goals (Araújo & Davids, 2016).

Cooperation emerges in sports teams as synergies are continually formed between the relatively independent degrees of freedom (dofs; i.e., the players), soft-assembled to function as a (sub)unit (e.g., in defensive or attacking phases of play) (Ribeiro et al., 2019). Globally, team synergies exhibit four key properties: dimensional compression, reciprocal compensation, interpersonal linkages, and degeneracy (Araújo & Davids, 2016). Couplings between players during synergy formation is predicated on the surrounding information and the collective attunement of teammates to shared affordances (Fajen, Riley, & Turvey, 2009) (providing opportunities to coordinate sub-unit actions in a sports team (Silva, Garganta, Araújo, Davids, & Aguiar, 2013)). Shared affordances explain how team dimensionality is reduced (known as dimensional compression as players re-organise) as well as the potential for one player's actions to influence opponent or teammate behaviours, so that task goals can still be accomplished (reciprocal compensation).

Understanding how team players form and develop functional synergies through learning designs has been investigated under a Constraints-led Approach (CLA) (e.g., Silva et al., 2016). This player-environment centred approach highlights the need to build representative learning tasks, using constraints manipulation, so that players can learn to use specified fields of information (a landscape of affordances) to functionally adapt their tactical performance behaviours (Passos & Davids, 2015). Through implementing this type of practice design, players become perceptually attuned to affordances of and for others, adjusting their actions rapidly to teammates and/or opponents' actions (Araújo, Davids, & McGivern, 2018; Silva et al., 2013). Particularly in volleyball, the ability to be perceptual attuned to different affordances can be crucial during the counterattack-phase when the opposition have possession of the ball (Mesquita, Palao, Marcelino, & Afonso, 2013). Accordingly, to overcome the unpredictability of the opponents' offensive organization, a team must exploit synergy (re)formation tendencies as players self-organise defensively increasing the odds to score.

Despite the extensive research undertaken so far, there is a need for investigations that determine coherent links between the task constraints manipulations and the resolution of tactical issues that emerge during competition. The impact of ecological learning tasks has been mainly evaluated using cross-sectional designs, usually conducted in segments of training sessions, which limits understanding of their performance benefits (e.g., Ribeiro et al., 2019). More longitudinal studies are required to extend knowledge about the tendencies underlying team synergy development over extended time periods. Due to their collaborative and interventionist nature, Action-Research (AR) designs could enhance understandings in this respect (Carr & Kemmis, 1986). Indeed, AR-designs offer opportunities to systematically reflect, monitor and undertake practice interventions, providing meaningful, contextualised insights on how team synergies evolve during training programmes. Despite recent implementations of AR-designs in physical education contexts (e.g., Farias, Hastie, & Mesquita, 2018), there remains a need for more AR applications in sports training contexts.

Didactical content for identification of the most relevant constraints on emergent behaviours of functional collective synergies are specific to each team sport (Hastie & Mesquita, 2016). For the design of representative learning tasks in non-invasive sports like volleyball, the specificity of information for players need to be considered. The Step-Game Approach (SGA) is a player-centred approach, didactically conceived for non-invasive sports, in which players are presented with step-by-step, tactical game-problems that constrain emergence of functional technical-tactical game-related behaviours (Mesquita, Graça, Gomes, & Cruz, 2005). Previous studies on SGA have sought to combine this approach with other pedagogical models (e.g., sport-education) to investigate the impact of hybrid models on learning (e.g., Araújo, Hastie, Pereira, & Mesquita, 2017). However, few studies have implemented SGA in training contexts using longitudinal designs, and even fewer have explored the potential of combining CLA and SGA (e.g., Ramos, Coutinho, Davids, & Mesquita, in press).

By integrating ecological with constructivist assumptions, it is considered that players can develop their own performance understanding through exploiting prior experiences and knowledge that mediates their perception-action coupling during competitive environments (Mahoney, 2002; Mckay & O'Connor, 2018). Thus, learning emerges since the players enhance and deepen their tactical understanding (i.e., acquiring specific game-related "knowledge of" the environment, in Gibsonian terms, to support their use of perception and action). Furthermore, these types of investigations may enhance understanding of how representative practice designs and didactical augmented informational constraints could influence emergence of synergy formation in sport teams.

To date, most studies investigating reciprocal compensation properties (measured, for instance, through synchrony between teammates) have been conducted within training environments (e.g., Gonçalves, Marcelino, Torres-Ronda, Torrents, & Sampaio, 2016). Currently, it remains unclear how opponents' actions and/or changing performance constraints might shape synchronous co-adaptation tendencies in competitive environments. Another key issue disregarded in previous research concerns how opponents' actions constrain the emergence of team synergies in non-invasive team sports, as well as how the complexity of different tactical configurations of play (i.e., the schema drawn from the relative spatial location of players (Gréhaigne & Goodbout, 2014)) could affect the (re)emergence of functional tactical patterns. Specifically, information derived under ecological constraints of competitive performance is needed to complement current understanding predicated on the study of team performance in practice designs. This type of research can also provide understandings of exactly how to design learning environments that simulate competitive performance constraints (enhance representativeness). In volleyball, one of the most relevant competitive constraints is the set, identified by Marcelino, Sampaio, and Mesquita (2012) as an important "micro-game" within the game. Effects of different set moments (e.g., initial and final) on subsequent performance have been studied in volleyball (e.g., Ramos, Coutinho, Silva, Davids, & Mesquita, 2017). However, there is a dearth of research investigating how team synchronisation tendencies evolve as function of performance perturbations at different set moments.

Therefore, combining key concepts from the CLA and SGA, and using an AR-design throughout a competitive season, the purposes of this study were twofold. First, we sought to analyse how the increased tactical complexity might impact on team synchronisation tendencies in a youth volleyball team during competitive performance. Second, we investigated how different set moments (i.e., initial, and final) might influence the team's synchronisation tendencies throughout the whole season.

We hypothesised that, across the season, the team would increase their synchrony as a function of experiencing more representative practice designs; however, we expected different synchrony levels to emerge as tactical complexity increased. Additionally, we hypothesised that, because of the learning designs applied, the influence of the final set moments on team synchronisation tendencies would decrease throughout the season.

Methods

Participants

Purposive and convenience sampling criteria were used to select fifteen female volleyballers, aged between 14 and 15 years (Sarstedt, Bengart, Shaltoni, & Lehmann, 2018). Participants had at least one year of specialized volleyball training and competitive experience. These participants were considered "information rich" and were at the beginning of the volleyball developmental pathway (Patton, 2015). This study was conducted over a competitive season, which lasted from September 2017 to June 2018, and comprised two distinct competitions: The Regional (September-January) and National championships (February-May). Globally, 143 training sessions and 32 official competitive matches were completed. On average, participants performed four training sessions (2 hours each) and one competitive match per week.

Ethical approval was granted by the Research Ethics Committee of the first author's institution, guided by the Declaration of Helsinki. Participants and parents were informed about the study's purpose, their scope of involvement and of their right to withdraw at any time. Data confidentiality was ensured, and informed consent forms were signed by both.

Study Design

This study followed an AR-design where the coach systematically and critically reflected about her practice, changing it as a result of her own reflections (Gubacs-Collins, 2007). An insider action-research approach was undertaken (i.e., the first author assumed the dual role of coach-researcher). This paradigm provided an advantage concerning the coaching-learning process designed to develop team synchrony tendencies (Coghlan, 2007). Aligned with the study's purposes, this design was adopted to extend our understanding on collective system dynamics by qualitatively analysing (following an interpretative paradigm) the processes underlying the emergence of synchronisation tendencies in a sports team over time. Globally, three AR-cycles were performed. Following recommendations of Gilbourne (1999), the first AR-cycle focused on the context exploration by players. During this cycle, the coach assessed the baseline of team synchrony behaviours and identified key tactical problems on counterattack that had to be resolved. According to these tactical needs, during the second and third AR-cycle the level of tactical complexity increased, through combining key CLA and SGA principles. For each AR-cycle, the team's synchrony levels were assessed during competitive matches, at different set moments. At the end of each AR-cycle, the reflections and identification of unresolved issues, in training sessions and competitive performance, guided the ensuing coaching intervention. This pedagogical intervention was monitored and evaluated, supporting its reconstruction and transformation throughout the competitive season.

Based on SGA pedagogical principles, each training session followed the tactical and didactical specificities required by volleyball performance. Three types of instructional tasks were implemented: acquisition, structuring and adaptation tasks (Mesquita et al., 2005). Concomitantly, the learning designs encompassed CLA principles, in which representative task constraints were manipulated to support the development of the team's synchrony levels under diverse ecological scenarios (Davids, 2009) (see table 1 and supplement 1 for further details). Due to the complexity inherent to the coaching-learning process, as well as to the intrinsic unpredictability of a competitive season, learning tasks and coaching interventions were daily adjusted.

As mentioned by Cook-Sather (2007), the coach-researcher attempted to deal with the consequences of her critical subjectivity. For instance, through regular debriefings held between the first author and two of the co-authors (who acted as 'friendly researchers'), the research team embraced a collaborative approach within the interpretation analysis. These sessions were opportunities to explore and critically discuss the influence of the coaching intervention on the team's synchronisation tendencies. This methodological approach ensured interpretative validity and minimized the risk of individual research bias (Patton, 2015).

Instructional validity

To guarantee that the CLA and SGA principles were combined, the coaching protocol was confirmed by one study author and one external observer not associated with the study. The external observer, who is an expert on sports pedagogy, analysed the documented training plans and the video records of training sessions. Rare disagreements were debated and resolved among the first author and the co-authors. A ten-item checklist was adapted from the studies of Práxedes and colleagues (2019) and Pereira and colleagues (2011) to test the behavioural fidelity of the coaching intervention. Accordingly, 18 training sessions - more than 10% of the total sample - were randomly examined for the presence of items included in Table 2 (Tabachnick & Fidell, 2007). Items 1, 2, 4, 5 and 6 encompass characteristics of SGA, while items 3, 7, 8, 9, and 10 are related to CLA. A 100% agreement level between observers confirmed the appropriate integration of both pedagogical approaches.

Table 1. A long-term overview of the coaching intervention combining CLA and SGA in the counterattack learning tasks designed

1st AR-cycle - Match 1 (M1) ***Functional Synchrony***		**2nd AR-Cycle – Match 2 (M2)** ***Introducing tactical complexity***		**3rd AR-cycle – Match 3 (M3)** ***(Re)Achieving functional synchrony***	
Tactical Counterattack Goals					
Offensive - Promote lateral and longitudinal coordination on in-system[1] organization with simple attack combinations		**Offensive** - Promote lateral and longitudinal coordination on out-system[2] - Promote lateral and longitudinal in-system organization with complex attack combinations		**Offensive** - Promote variability on set action according to the opponents' blockers - Explore the attack by middle-blockers	
Defensive - Block-defense relationship on 1x1 situations		**Defensive** - Block-defense relationship on 1x2 situations against the outside-hitters and the opposite		**Defensive** - Block-defense relationship on 1x2 situations for all spikers, including middle-blockers	
SGA	CLA	SGA	CLA	SGA	CLA
Task type: <u>Acquisition:</u> - Individual block actions - Collective defense action on 1x1 situations - Block-defense relationship on 1x1 situations **Pedagogical strategies:** - Cue perception	**Designing actions' opportunities** - Avoid attack repetition by the previous player **Task constraints** <u>Rules:</u> -Player must perform different attack actions (e.g., roll shot followed by tip) on a sequence of consecutive attacks	**Task type:** <u>Structuring:</u> - Double-block actions (zone 4 and zone 2) - Collective defense actions on 1x2 situations -Block-defense relationship on 1x2 situations **Pedagogical Strategies:** -Tactical Understanding - Strategic game-plan (identification of best and worst spiker, digger, and blocker)	**Task Constraints** <u>Score:</u> - Mini set from 0 to 15 points - Set starts at 17/17 until 25 points. Every ball punctuates. **-** Reward attacks scored during out-system situations or with complex attack combinations - Reward block and dig actions **Complexity** - 6x6 with two setting options during in-system situations	**Task type:** <u>Adaptation:</u> - Double-block actions (zone 3) - Collective defense action according to opponents' tactical game model **Pedagogical Strategies:** - Tactical Understanding - Strategic game-plan (definition of specific block-defense priorities for each rotation according to different set moments)	**Task Constraints:** <u>Score:</u> - Set starts from 20/20 to 25. Sequences of 5 balls to the same team. At maximum team could win 3 points, such as: 5-0, 3 points; 4-1, 2 points; 3-2, 1 point -Reward middle-blockers' attacks and block actions as well. **Representativeness** - Block and defense according to strategic game-plan principles **Complexity** - 6x6 with free setting options during in-system situation

Note: [1] In-system, meaning that all hitters available; [2] Out-system, meaning that only the outside-hitters and the opposite available (adapted from Lorenzo, Afonso, & Mesquita, 2018).

Table 2. Instructional checklist

Elements of the training session	Present	Absent
1. Create tactical problem as the center of learning tasks organization.		
2. The coach explained the task, observed individual and collective behaviours, and used questioning to induce players' reflection.		
3. The tasks and game complexity increased throughout the season.		
4. All training sessions included acquisition, structuring and/or adaptation tasks.		
5. The tasks frequently included accountability criteria.		
6. The training sessions were closed with SSCG or thematic game stressing the application of technical and tactical skills initially addressed.		
7. Manipulation of constraints of the full game were performed.		
8. All tasks were constrained in terms of rules, space, and/or time.		
9. All tasks required the exploration of different performance solutions by the player.		
10. All tasks were built in order to ensure that learning designs represent the competitive performance environments.		

Recording and 2D reconstruction procedures

The matches analysed were played on a volleyball court with dimensions of 18 x 9 m (width x length). Performance sequences were filmed by a digital camera positioned above (2 m) and behind (5 m) the court. The camera zooming rate was fixed to simplify the motion image processing. Images were captured at a frequency of 25 Hz and a resolution of 1920 x 1080 pixels. Positional coordinates were recorded through TACTO software (version 8.0) at an accuracy level (i.e., the difference between the virtual coordinates recorded and the real coordinates) higher than 95% at 25 Hz (Fernandes, Folgado, Duarte, & Malta, 2010). The court was calibrated using six calibration points, located respectively on the ends of the court (two points) on the lateral 3m line (two points), and over each antenna (two points) (Duarte et al., 2010). The players' working point (projection of the gravity centre on the floor locating the mean distance between player's feet) was tracked using a computer mouse in a slow-motion video. This software package provided players' 2D virtual coordinates (expressed in pixels). Conversion from virtual to real spatial coordinates (expressed in meters) was performed using the Direct Linear Transformation (2D-DLT) (Duarte et al., 2010). Table 3 provides a detailed description of matches and sequence selection criteria as well as the number of sequences analysed per match. The average length of sequences was up to 7.6 seconds.

Table 3. Detailed description concerning to the matches and sequences' selection criteria and the number of sequences analysed per match

Matches' selection criteria		
Competitive Moment	**Opposition Level**	**Frequency of counterattack (KII) practice**
Matches from the regional and national championship	Matches against the top four ranked teams in the previous season	Number of learning designs (i.e., training tasks), related with counter-attack phase, performed during the week before each match.
Sequences' selection criteria		
Only the complex II and II were considered. The data were collected from the instant when the opposition player performed the first ball contact (pass or dig), to the instant when the attacker touched the ball (during an attack by the player of the team under analysis)		

Description of the matches and sequences selected						
				Number of sequences		
	Competitive Moment	Opposition Level	Frequency of (KII)	Match	Initial Set Moment	Final Set Moment
Match 1 (M1) *1st AR-cycle*	Regional Championship, 1st round 15th October, 2017	2nd place	7	24	7	7
Match 2 (M2) *2nd AR-cycle*	Regional Championship, 2nd round 2nd December, 2017	4th place	7	24	7	7
Match 3 (M3) *3rd AR-cycle*	National Championship, 1st round 21st April, 2018	2nd place	6	24	7	7

Note: *The complex II corresponds to the counterattack-phase, while the complex III regards to the transition of transition phase (e.g., see Lorenzo et al., 2018)*

Reliability

Six playing sequences (two per match) analysed were randomly selected and the data trajectories of players were re-digitised by the same operator. The data were evaluated for reliability and accuracy using the coefficient of reliability (R) and technical error of measurement (TEM) (Goto & Mascie-Taylor, 2007). The intra-observer results depicted good accuracy and reliability levels (%TEM = 0.5, R = 0.99).

Cluster-Phase Method (CPM)

Kuramoto and Nishikawa (1987) developed the Kuramoto order parameter to analyse systems whose oscilatory units tend to infinity (Strogatz, 2000). Overall, the CPM enabled us to compute the means and continuous group synchrony levels, ρ_{group} and $\rho_{group}(t_i)$, as well as each individual's relative phase, θ_k (Richardson, Garcia, Frank, Gergor, & Marsh, 2012). This method was successfully applied by Ribeiro and colleagues (2019) to assess a multilevel hypernetworks approach to capture synchronisation tendencies (i.e., how players synchronised their behaviours with the simplices (sub-groups of players, e.g., 3vs.2) with which they interacted during competitive performance). In this study, we adapted the expressions used by Ribeiro et al. (2019) to compute the cluster phase, using a global measure, cluster-amplitude, to capture team synchronisation in each time-series. Here, synchronisation refers to the coordination patterns developed by players over time that allow them to temporarily form functional synergies to achieve shared performance goals (i.e., team's synchrony). Specifically, we replaced the simplices sets Γ_j, previously employed in the model of Ribeiro et al. (2019), by the set of players composing team Γ_A. Therefore, Γ_A and its size n_A, is defined by the number of players that compose Team A. The expressions used are described below, from (1) to (4).

Given the phase time-series obtained through Hilbert transformation, $\theta_k(t_i)$, for the k^{th} player movements measured in radians [-π π], where $k = 1, \cdots, N$ and $i = 1, \cdots, T$ time steps, the Team A or *cluster* phase time-series, $\overline{\emptyset}_A(t_i)$, can be calculated as:

$\acute{r}_A(t_i)\frac{1}{n_A}\sum_{k\in\Gamma_A}\exp(i\theta_k(t_i))$ ....(1)

and:

$\overline{\emptyset}_A(t_i)\ atan2(\acute{r}_A(t_i))$ ....(2)

where $i = \sqrt{-1}$ (when not used as a time step index), $\acute{r}_j(t_i)$ and $\overline{\emptyset}_j(t_i)$ comprise the resulting cluster phase in complex and radian form, respectively.

Ultimately, the continuous degree of synchronisation of Team A $\boldsymbol{\rho}_{\Gamma_A}(\boldsymbol{t_i}) \in [\mathbf{0}, \mathbf{1}]$, i.e., the cluster amplitude $\boldsymbol{\rho}_{\Gamma_A}(\boldsymbol{t_i})$ at each time step t_i can be computed as:

$\rho_{\Gamma_A}(t_i) = \left|\frac{1}{\mathrm{n}_A}\sum_{k\in\Gamma_A}\exp\left(i(\theta_k(t_i)\ \overline{\emptyset}_A(t_i))\right)\right|$ ....(3)

and the temporal mean degree of group synchronisation, $\boldsymbol{\rho}_{\Gamma_A} \in [\mathbf{0}, \mathbf{1}]$, is computed as:

$\rho_{\Gamma_A}\frac{1}{T}\sum_{i=1}^{T}\rho_{\Gamma_A}(t_i)$ ....(4)

To summarize, first, we calculated the Hilbert transform of each sequences of values for the longitudinal and lateral players' coordinates. The phase (i.e., local amplitude and local variability) of the Hilbert transform is the phase of each player. Then, we calculated the phase of the cluster (i.e., all the team players) by adding all the values of each player's phase. After that, we computed the differences of each player's phase with respect to the phase of the cluster (i.e., the team), and calculated the mean of those differences. The cluster amplitude value corresponds to the inverse of the circular variance of $\emptyset k(ti)$. Therefore, if $\rho\Gamma_A$ = 1, the group is in complete intrinsic synchronisation (intra-team relationships), and if $\rho\Gamma_A$ = 0, the group is completely unsynchronised. All the computations for calculating the cluster amplitude were performed using specific routines implemented in GNU OCTAVE (version 5.1.0).

Data Analysis

A 3 (matches) x 2 (set moments) x 2 (court direction) repeated-measures ANOVA was used to calculate differences in the cluster amplitude mean values between matches, and as a function of set moments (initial and final) and court directions (lateral and longitudinal). The equality of variances was assumed once groups were composed of equal sample sizes (Field, 2009). Possible violations of sphericity assumption in the repeated-measures of the within–participant factors were checked using Mauchly's test and, when necessary, the Greenhouse-Geisser or Huynh-Feldt correction procedure were used to adjust the degrees of freedom. Pairwise differences were assessed with Bonferroni post-hoc. Paired t-tests were used to calculate the cluster amplitude mean differences between set moments. The differences inter set moments were calculated through standardised mean differences (SMD), via Cohen's d, with 95% confidence intervals. The level of statistical significance was set at $p = 0.05$. Effect size values were determined by calculating partial eta squared (ηp^2) (Levine & Hullett, 2002), considered as small ($\eta p^2 < 0.06$), moderate ($0.06 \leq \eta p^2 < 0.15$) or large ($\eta p^2 \geq 0.15$) (Cohen, 1988). Inferential statistical procedures were conducted in SPSS 25.0 software (IBM, Inc., Chicago, IL).

Results

Figure 1 summarises the descriptive statistics of the team's cluster amplitude in each AR-cycle, as function of set moments and court directions.

Over the season, results indicated small significant differences for synchronisation tendencies in lateral ($F_{(1,945)} = 710{,}909$; $p < 0.001$, $\eta_p^2 = 0.02$) and longitudinal ($F_{(1,970)} = 737{,}711$; $p < 0.001$, $\eta_p^2 = 0.02$) court directions. In the lateral direction, significant differences in synchrony levels ($p < 0.001$) were observed between all matches, with the lowest level of team synchrony being attained in the second match, and the highest level in the first match. In the longitudinal direction, results revealed significant differences in synchronisation between M1-M2 and M2-M3 ($p < 0.001$). However, we did not observe statistical differences in synchronisation levels from the first to the third match ($p = 0.214$). The lowest longitudinal synchrony level, during the counterattack phase, was observed in the second match, whilst the highest level was verified in the third match.

Analysis of team synchrony according to specific set moments revealed significant differences in team synchrony between the initial and final set moments in lateral ($t_{(45087)} = 11{,}176$; $p < 0.001$, $d = 0.05$) and longitudinal ($t_{(45076)}$

= 21,417; p < 0.001, *d* = 0.15) court directions, with the team displaying higher levels of asynchrony during the final set moments.

Throughout the season, we observed small significant differences in team synchrony levels in lateral ($F_{(1,945)}$ = 129,1789; p < 0.001, η_p^2 = 0.01) and longitudinal ($F_{(1,980)}$ = 47,037; p < 0.001, η_p^2 = 0.003) court directions during initial set moments. Results depicted significant differences (p < 0.001) in both court directions at the beginning of the sets, with the team progressively increasing synchronisation levels in lateral and longitudinal directions over the season.

Regarding the final set moments, results revealed significant differences in team synchrony in lateral ($F_{(1,945)}$ = 178,886; p < 0.001, η_p^2 = 0.01) and longitudinal ($F_{(1,960)}$ = 680,630; p < 0.001, η_p^2 = 0.05) court directions across the season. Although in the second match the team had decreased their synchronisation tendencies for both court directions, at the end of the season (third match analysed) the team had increased their synchrony levels laterally and longitudinally. Moreover, we observed significant differences (p < 0.001) between matches in both court directions.

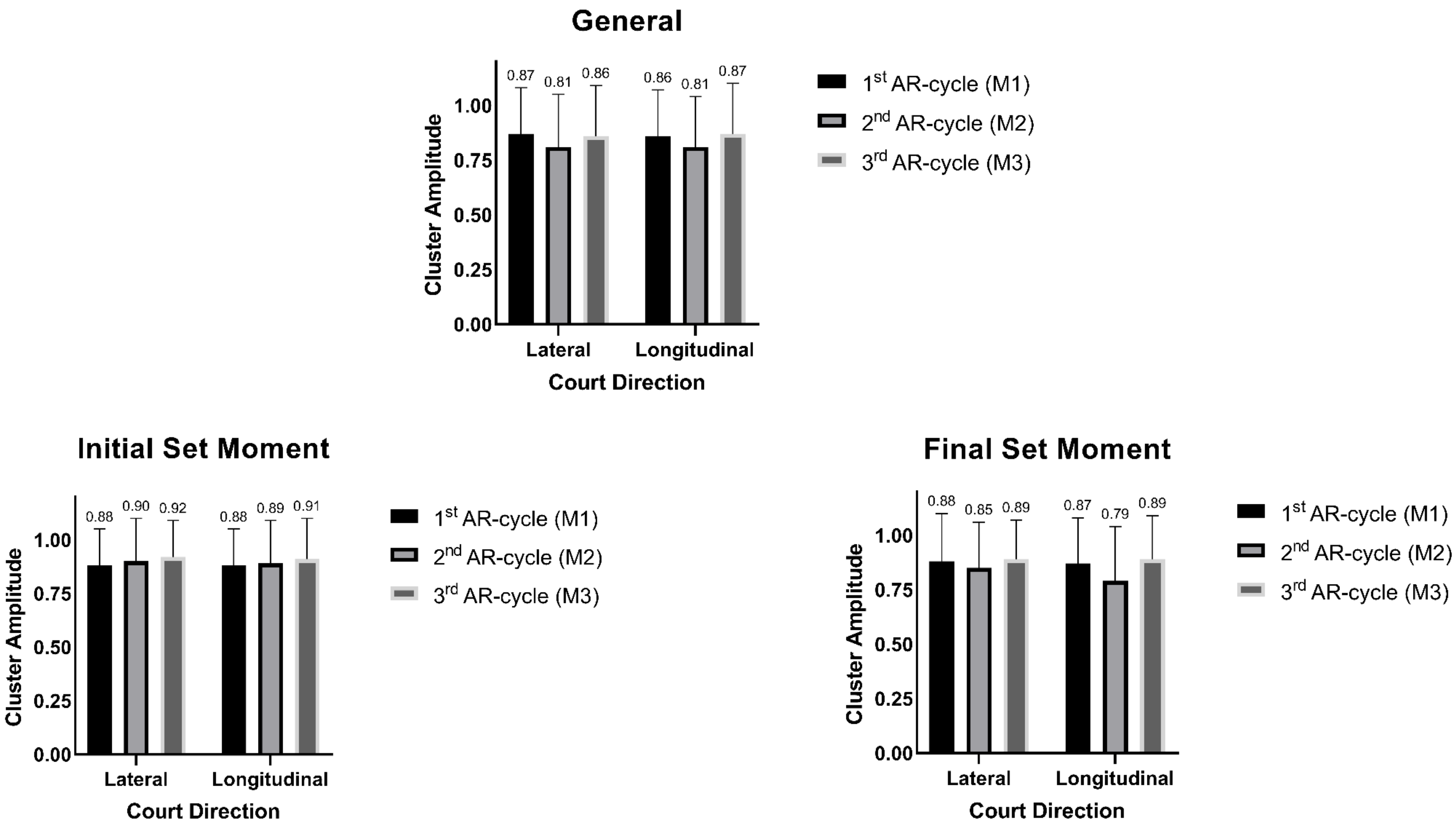

Figure 1. Mean and standard deviation values of cluster amplitude during each AR-cycle (match 1, match 2, match 3) as function of set moment (initial and final) and court directions (lateral and longitudinal)

Discussion

By implementing an AR-design throughout a competitive season and combining CLA and SGA approaches, this study investigated the impact of increased tactical complexity on team's synchrony in a volleyball team. We also investigated whether the synchronisation tendencies could be shaped at different set moments. Overall, results revealed reductions in intra-team synchrony when tactical complexity of counterattacking play increased (second AR-cycle). However, similar levels of between-player synchrony emerged between the first and third AR-cycles. Additionally, our findings highlighted the final set moments as an environmental constraint which progressively reduced its impact on team synchronisation tendencies. The insider AR-design afforded the capacity to closely monitor the coaching-learning processes changes underlying the development of a team's synchronisation tendencies throughout a competitive season. Indeed, the engagement of a coach-researcher in the volleyball training context supported regular adjustments of the design of ecological and sport-specific didactical practice tasks according to a team's developing tactical needs.

The first AR-cycle focused on the diagnosis of the team's current synchronisation tendencies, as well as the identification of the main tactical changes that needed to be resolved to enhance sport performance. The initial tactical modelling for the counterattack-phase corresponded to a simple block-defense organization (i.e., single blocker with five remaining defenders filling the centre of the court). In order to develop the players' co-adaptive interactions under different ecological constraints, during this AR-cycle, the training intervention was conceived to afford opportunities for players improve their capacity to perceive the most relevant tactical information sources within similar representative game situations. Accordingly, the performance analysis of the first match, portrayed lateral and longitudinal synchronisation values close to 1, indicating high levels of functional synchrony between teammates within this tactical counterattacking organisation.

For participants to enhance adaptability and the number of collective tactical options, during the second AR-cycle, the coach increased tactical complexity in the defensive (double-block on zone 4 and zone 2) and offensive (complex attack combinations) counterattacking subphases. For example, learning designs emphasised co-adaptative movements between the middle-blocker and the outside-hitter and opposite. As expected, during the second match, significant reductions were observed in team synchrony levels in both court directions, possibly due to increasing tactical complexity that was slowly being instigated during practice. Indeed, as suggested by Balagué and colleagues (2013) the introduction of complexity in a system (e.g., sports team) implies a co-adaptation of the informational channels that supports system self-organization properties. This process in a sports team (complex system) requires significant amounts of practice time spent training under meaningful ecological constraints. The same tendency for a decrease in synchronisation between players' actions was detected in the final set moments of the second match. The final set periods have been previously identified by Marcelino et al. (2012) as critical environmental game constraints, which can determine emergence of victory or defeat. Our findings corroborated this assumption, once when compared to initial set moments, the team's synchrony levels during the final moments were lower. Particularly when tactical complexity increased (second match), the final set moments seemed to influence the players' ability to identify the most relevant tactical constraints, influencing their tactical synchronisation capacity.

Interestingly, from the first to the second AR-cycles the team's synchrony levels were elevated at initial set moments. A possible explanation for this finding may be because that they developed a basic strategic game-plan. In order to improve the team's tactical awareness, during the second AR-cycle, the coach started to identify, together with the players, simple tactical game constraints to focus on from early competitive interactions with the opposition (e.g., who was the best spiker or who was the worst receiver). Afterwards, during an interactive and constructive discussion, the coach and players co-defined tactical game principles that may be needed to gain tactical advantage over their opponents. Gradually, during initial competitive moments, the players might have been able to recognise these most relevant performance constraints interacting, between each other, to anticipate and respond to the opposition's tactical actions.

At the end of the third AR-cycle, the team revealed values of synchrony similar to the first AR-cycle. This outcome supports the assumption that, at the end of the season the team (re)achieved higher levels of functional synchronisation using a more complex tactical game model. This finding highlights the importance of practice time needed to develop tactical awareness, which impacted on collective synchronisation tendencies. From the second to the third AR-cycles, aligned with the increase in the team's tactical performance complexity, the analysis of opposition performance, during match preparation, also became more refined (e.g., defining block-defense priorities per each player's rotation at different set moments). This coaching intervention seemed to improve the participants' tactical understanding. Concomitantly, the learning tasks began to be constrained by analyses of the next immediate opponent's performance characteristics at distinct set moments. Following recommendations of Travassos, Duarte, Vilar, Davids, and Araújo (2012), thematic games were developed and implemented in practice designs which were constrained by implementation of specific 'rules' (e.g., setting options), incentives (e.g., extra points to positive double-block contacts) and scenarios such as initial set scores (e.g., the set starting on 20-20).

The continuous exposition of this ecological and sport-didactical coaching intervention facilitated the participants' perceptual attunement to affordances of and for others that, in turn, allowed them to adjust their tactical behaviours as performance constraints changed (e.g., the score at final set periods). In a volleyball match, the final set moments can dictate if a team wins or loses, therefore the pressure is huge and can interfere with team synchronisation processes (i.e., reducing its levels). Possibly in reason of the improvements on players' perceptual attunement to shared affordances the highest levels of the team's synchrony were observed during the initial and final set moments of the third match, indicating that participants had acquired the capacity to functionally re-organise their tactical behaviours at critical competitive moments.

Although this study extends our understandings about how to analyse and implement practice designs that enhance synchronisation tendencies in volleyballers, it only provided a global macroscopic view of the team's tactical patterns. Future research needs to analyse synchronisation tendencies during counterattacks (e.g., with and without ball possession). These initial findings suggest how research on team sports performance enhancement could implement AR-designs within training and competitive contexts.

Our results imply that coaches could explore co-adaptation tendencies in sports teams through development of players' tactical awareness and the design of representative learning tasks. However, both must be congruent with specificities of team tactical game models and principles established for each strategic game-plan and needs. Additionally, findings suggest how coaches could manipulate the set scores when creating training scenarios to simulate player interactions needed under meaningful contexts. Finally, exploration of different, but complementary, pedagogical approaches may help coaches to develop team tactical behaviours.

Finally, as reported in the study of Duarte and colleagues (2013), the statistical differences observed in the current study revealed small effect sizes, which might limit our interpretations of the data, suggesting the need for further empirical clarification. Another limitation of this study is that its analysis focused on the "phase" of synchronisation in the trajectory of a dynamical system (e.g., team coordination in volleyball) as a combination of "phase" and "amplitude". Therefore, a movement in a different direction with a different velocity produced due to a movement of another player cannot be quantified as a synchronised behaviour, described by the term "phase synchronisation". Thus, in future studies, there is a need to scrutinise whether it is more adequate to consider players as "oscillators" (whose phase is adjusted) instead of vectors (whose direction is adjusted).

Conclusion

This study highlighted the relevance of team synergetic behaviours expressed in the synchronisation tendencies emerging during the counterattack phase in a non-invasive sport. Results suggested that introducing more complex tactical organisations lead to a reduction in a team's synchronisation, with the (re)achievement of functional synchrony being facilitated by combining CLA and

SGA approaches in practices designed to enhance players' tactical awareness during competition. Results also implicated the final set moment as an environmental constraint that impacts greatly on team synchrony. From a research methodology perspective, an insider AR-design provided relevant contextualised understandings about the planned development of a team's synchronisation tendencies.

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Empirical Study 3

How can team synchronisation tendencies be developed combining Constraint-led and Step-Game approaches? An action-research study implemented over a competitive volleyball season

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Abstract

Combining Constraint-led (ecological) and Step-Game (constructivist) approaches through an Action-Research (AR) design conducted throughout a competitive volleyball season, this study aimed to: (i) analyse the impact of increased tactical complexity on lateral and longitudinal collective synchronisation tendencies during defensive and offensive counterattack-subphases, and (ii) examine how opposition attacking contexts (i.e., playing in *full*-system or *in*-system) might influence synchronisation tendencies throughout each counterattack-subphase. Performance of a youth team, comprised of fifteen players, was studied across three AR-cycles. The team's competitive performance was analysed through three competitive matches (one per cycle). Team synchronisation tendencies were evaluated using the cluster-phase method and a 3 (matches) x 2 (counterattack-subphases) x 2 (opposition attacking contexts) x 2 (court directions) repeated-measures ANOVA were used to calculate the differences in cluster-amplitude mean values. Results showed that increments in tactical complexity (second AR-cycle) were followed by decreases in collective synchronisation tendencies, which were (re)achieved during the third AR-cycle, possibly due to the ecological-constructivist coaching intervention. Our findings imply that coaches could design representative and specific-didactical learning environments, predicated on a team's tactical needs and strategical ideas from a game-plan, framing player intentionality. Results also support the use of questioning strategies to narrow players' attentional focus, stimulating perceptual attunement to relevant constraints emerging in performance. Finally, the insider AR-design provided valuable contextualised insights on coaching interventions for developing collective coordinative structures.

Keywords: ecological-constructivist intervention, action-research, synchronisation tendencies, practice design, sport pedagogy, volleyball

Introduction

Throughout the past decade, several researchers have sought to comprehend how players synchronise actions during successful, competitive sport performance (e.g., Chow, Davids, Shuttleworth, & Araújo, 2020). Considering team sports as complex dynamical systems, supported by ecological dynamics fundamentals, the term *'team synergy'* has emerged in sports science to explain how players interact to satisfy the competitive demands without compromising collective functionality (Araújo & Davids, 2016).

Considered as emergent phenomenon, team synergies are groups of relatively independent degrees of freedom (e.g., players) that functionally re-organise to achieve planned goals (Riley, Richardson, Shockley, & Ramenzoni, 2011). Player coupling in synergy formation is underpinned by perceptual attunement to shared affordances (i.e., awareness of action opportunities) (Gibson, 1979; Silva, Garganta, Araújo, Davids, & Aguiar, 2013). To date, studies have mainly focused on analysis of the synergetic property of *dimensional compression*, with *reciprocal compensation* being less scrutinised (Ramos et al., 2020). The few studies investigating reciprocal compensation have evaluated synchronisation tendencies (ST) emerging between players using the cluster-phase methodology (Ribeiro et al., 2020).

Investigations about how team synergies emerge and evolve have been conducted using the Constraint-led Approach (CLA) (Silva et al., 2016). This player-environment-centred pedagogical approach advocates manipulation of informational constraints to build representative learning scenarios, supporting a tight action-perception coupling to utilise affordances available in training and competition (Woods, McKeown, Shuttleworth, Davids, & Robertson, 2019). Continuous representative practice allows players to become perceptually attuned to affordances *of* and *for* others, stimulating their ability to efficiently (re)organise collective behaviours in competition (Araújo, Davids, & McGivern, 2018). In volleyball based on opposition tactics (e.g., high frequency of line attacks), a practice task can be constrained by rules (e.g., hitters only attacking the line) to induce the block-defence ST needed to overcome opponents in competition. The CLA research has mainly evaluated ST in invasive team-sports.

Possible effects of other training processes on development of ST need more research attention (Ramos et al., 2020). The impact of training protocols, which are commonly assessed over brief timescales, on synergy formation between players has overfocussed on an *'end-product'* (i.e., comparing initial and final practice stages), ignoring the underlying processes.

Development of functional interpersonal synergies needs to be aligned with the specificities, nature, and didactical content of each team sport (Hastie & Mesquita, 2016). Despite their relevance, these issues have been neglected in the literature. Conceptually grounded on constructivist assumptions, the Step-Game Approach (SGA) considers the nature of non-invasive games, like volleyball (Mesquita, Graça, Gomes, & Cruz, 2005). This player-centred approach offers didactic perspectives by structuring the teaching-learning process and defining practice tasks and strategies at different learning stages. Therefore, the development of ST can be didactically supported. The SGA advocates the development of players' abilities through step-by-step challenges, establishing meaningful couplings between tactical demands and technical skills (Mesquita et al., 2005). To exemplify, in volleyball, the blocking technique, using the 'steps-approach-arms' position, can be practised within a tactical activity that develops reading and anticipation of the opposition setter's decisions.

Integrating ecological (CLA) and constructivist (SGA) methodologies could extend our knowledge about how representative learning environments, manipulating specific-didactical constraints, might influence the development of functional coordinative structures (Ramos et al., 2020). Given its cyclic and interventive nature, Action-Research (AR) designs could be helpful for monitoring the integration of ecological-constructivist approaches over extended time-periods (Carr & Kemmis, 1986). The systematic monitoring of practice programmes can provide contextualised insights about how ST emerge, persist and evolve during pedagogical interventions.

In volleyball, in the counterattack game-phase, lateral and longitudinal ST are preponderant once the opposition have possession of the ball. To deal with unpredictability of opposition actions and gain a tactical advantage during counterattacking-subphases, players must become perceptual attuned to the most relevant affordances. Specifically, the opposition attacking context, described in volleyball literature as ‘setting options/conditions’ or ‘number of hitters available’, is a key constraint influencing a team’s performance during competition (Laporta, Afonso, & Mesquita, 2018). Yet, there is a gap in understanding about how opposition tactics/strategy might shape the (re)emergence of functional team synergies in play. It is pertinent to explore how attunement to opposition attacking options could be developed in practice by integrating ecological with constructivist and didactical-specific approaches. It remains unclear how increasing tactical complexity during practice may impact on quality of team transitions between functional synergetic states (*system metastability*) (Hristovski, Davids, & Araújo, 2009).

Adopting an AR-design over a competitive volleyball season, this study sought to integrate CLA-SGA principles to: (i) analyse the impact of increasing tactical complexity on lateral and longitudinal team ST during defensive and offensive counterattack-subphases; (ii) to examine how opposition attacking contexts might influence team ST during each counterattack-subphase. We hypothesised that throughout the season, the team would: (i) change ST as function of increases in tactical complexity; (ii) increase its synchrony in both counterattack-subphases as a result of representative practice designs; (iii), reduce the influence of opposition attacking context on their ST.

Methods

Participants

Fifteen female players (14 and 15 years-old), with at least one year of formal competitive experience, were selected through purposive and convenience sampling criteria (Patton, 2015). These participants were viewed as “information-rich” because they were at the beginning of their sporting experience and due to their ability and willingness to participate. This study was conducted from September 2017 to June 2018, encompassing Regional (September-January) and National championships (February-May). Overall, 143 training-sessions and 32 official matches were undertaken. On average, four training-sessions (2-hour long each) and one match were experienced per week.

Guidelines from the Helsinki Declaration were followed, and ethical approval was granted by the first author's institution Research Ethics Committee. Participants and their parents were informed about the scope of intervention, and the right to withdraw from the study at any time, without penalty. Confidentiality was ensured and informed consent forms were signed.

Study Design

An AR-design was adopted in which the coach ongoingly and critically reflected about her practice, adapting it according to self-reflections (Carr & Kemmis, 1986). Specifically, an insider-AR approach was implemented, with the first author assuming the dual role of coach-researcher. This paradigm provided a privileged viewpoint about the teaching-learning processes underlying ST development (Coghlan, 2007). Specifically, the insider-AR was used to extend relevant understanding about team collective dynamics by qualitatively examining – framed upon an interpretative paradigm – processes inherent to the emergent ST in each counterattacking-subphase. The ST observed in each counterattacking-subphase were recorded during three competitive matches (one per-cycle), considering the opposition attacking contexts encountered. The 1st and 2nd AR-cycles lasted 4 months each (September-December 2017, and December 2017 - March 2018, respectively). The 3rd AR-cycle lasted 3 months (April-June 2018).

The first AR-cycle focused on context exploration by players (Gilbourne, 1999), with the coach diagnosing the baseline ST, identifying the main tactical problems at each counterattack-subphase. The remaining two AR-cycles focused on increasing tactical complexity in practice designs by integrating key CLA-SGA principles. Recorded reflections, aligned with the unresolved problems identified in training and competition, guided subsequent interventions. This design enabled monitoring and adjustments of the coaching intervention, supporting a reframing and transformative process. Based on SGA principles, each training-session sought to enhance technical and tactical performance. The didactical content development comprised acquisition, structuring, and adaptation instructional tasks (Mesquita et al., 2005). These learning tasks were based on

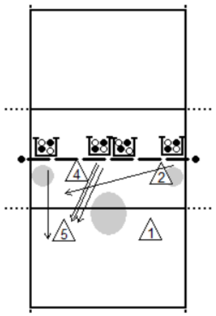
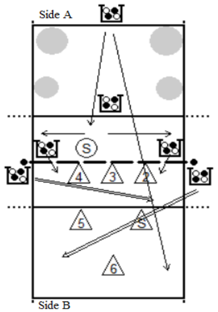
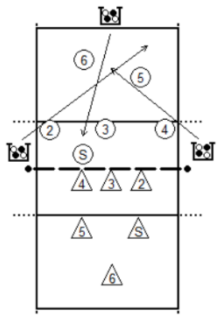
CLA principles, in which manipulation of representative task constraints was designed to promote development of ST (Woods et al., 2019). It is important to emphasise that, in this study, we did not seek to increase the team's levels of ST by applying a 'pre-stablished interventional protocol'. Rather, by acknowledging the intrinsic complexity and unpredictability of a competitive season, both learning tasks and coaching interventions were adapted daily (exemplified in Table 1).

To ensure the study's interpretative validity, and to reduce the chance of individual research bias, regular debriefings occurred between the first author and two 'friendly researchers' (co-authors of this study) (Patton, 2015). These meetings provided opportunities for reviewing, in a collaborative and constructive fashion, the influence of the CLA-SGA coaching intervention on the team ST development.

Table 1. Overview about the coaching pedagogical intervention implemented over the competitive season, which combined CLA and SGA principles to develop collective synchronisation tendencies in each counterattack-subphase

	1st AR-cycle	2nd AR-cycle	3rd AR-cycle
No-ball (defensive)	- Lateral synchrony on 1x1 (block-defense) situations, against opponents playing *in*-system	- Block-defense synchronisation in 1x2 organisation on zone 4 and 2, against opponents playing *in*-system - Block-defense synchronisation in 1x3 organisation on zone 6, against opponents playing *in*-system	- Block-defense synchronisation in 1x2 organisation on zone 3, against opponents playing in-system - Collective block-defense priorities according to the opposition attacking contexts
Ball (offensive)	- Lateral and longitudinal synchronisation tendencies with *in*-system simple attack combinations	- Lateral and longitudinal synchrony of simple attack combination during *out*-system situations - Collective synchronisation tendencies of complex attack organisation	- Variability on set action as function of opponents' blockers - Variability on offensive organisation according to the setting conditions

1st AR-cycle SGA	1st AR-cycle CLA	2nd AR-cycle SGA	2nd AR-cycle CLA	3rd AR-cycle SGA	3rd AR-cycle CLA
Task type Acquisition: - Individual dig actions - Individual block actions - Collective dig and set actions on 1x1 situations **Pedagogical strategies** - Cue perception (anticipate attackers' intentions)	**Task constraints** - Starting position for dig with eyes closed - Good transition measured considering the quality of dig and set transition (e.g., scored with 1 point)	**Task type** Structuring: - Collective block and defense against attack on zone 4 and 2 - Triple block against attack on zone 6 **Pedagogical Strategies** -Tactical Understanding - Strategic game-plan (exploring opponents' weaknesses)	**Task Constraints** - Blocking with decision-making (i.e., the opponent setter determined who will block) at different attack tempos - setting options fully constrained to narrow the work on block-defense **Complexity** - 6x6 with two setting options during *in*-system situations	**Task type** Adaptation: - Collective block-defense against attack on zone 6 **Pedagogical Strategies** - Tactical Understanding - Strategic game-plan (block-defense priorities according to opponents' attacker in each rotation) - Cue Perception (anticipate opponent's setter intention)	**Task Constraints** 6x6 rules/score: - setting options briefly constrained to narrow the work of block-defense - positive block contact or defense are rewarded with one extra point. -Complex offensive combination playing *in*-system rewarded with two extra points

Example of block-defense learning task					
Description	*Graph*	*Description*	*Graph*	*Description*	*Graph*
Defenders must start with eyes closed. One sequence of three attacks: (1) middle-attack to zone 5 with set transition by z1; (2) line-attack for block and defense; (3) middle-attack to zone 5 and cross attack to zone 4 **Questioning Examples:** -Where are you looking when you open your eyes? Ball? Hand? How did you end the set? How were your shoulders?		Sequences of two balls: (1) *In*-system ball tossed to the setter (S), who can set free to zone 4 or 2 (side A). Attack from the box and floor at the same time, against block and defense respectively; (2) freeball tossed to the side B, so that can perform a complex offensive combination to one of the spots highlighted. **Questioning Examples:** Did you have a good angle to attack on that trajectory? Did you jump on the right tempo? Why? Why not?		Conditional 6x6 format – sequences of 5 balls: (1) *in*-system ball tossed to the setter who can choose to set on zone 3, 6 or 4; (2) an attack from zone 2; (3) *in*-system ball tossed to the setter who can choose to set on zone 3, 6 or 2; (4) an attack from zone 4; (5) in-system ball tossed to the setter who set free. The set starts at 10/10 – positive block and dig contacts rewarded with one extra point **Questioning Examples:** -Why did you set to that zone? Which were her opponents? Did you see the block open? So why did you dig there?	

Instructional validity

To ensure the CLA-SGA combination, the coaching intervention was confirmed by one co-author, and one knowledgeable, independent observer not associated with the study. The independent observer analysed the documented training-plans, and the training video records. The few disagreements were resolved consensually. A ten-item checklist was adapted according to evidence from studies by Pereira and colleagues (2011), and Práxedes and colleagues (2019) to assess behavioural fidelity of the coaching intervention. Eighteen training sessions (10% sample) were arbitrarily analysed for the presence of the items included in Table 2 (Tabachnick & Fidell, 2007). A 100% agreement level between observers ensured the suitable CLA-SGA combination.

Table 2. Instructional checklist

Elements of the training session	Present	Absent
1. Create tactical problem as the center of learning tasks organization.		
2. The coach explained the task, observed individual and collective behaviours, and used questioning to guide players' tactical understanding.		
3. The tasks and game complexity increased throughout the season.		
4. All training sessions included acquisition, structuring and/or adaptation tasks.		
5. The tasks frequently included accountability criteria.		
6. The training sessions were closed with SSCG or thematic game stressing the application of technical and tactical skills initially addressed, as well as promoting the emergence of the synchronisation tendencies at each counterattacking-subphase previously emphasised.		
7. Manipulation of constraints of the full game were performed, so that players can guide their attentional focus for specific tactical coordinative structures.		
8. All tasks were constrained in terms of rules, space, time and/or opposition attacking contexts.		
9. All tasks required the exploration of different performance solutions by the player.		
10. All tasks were built to ensure that learning designs represent the demands of competitive performance environments.		

Variables

The counterattack-phase comprises the block, dig, set and attacking actions (Eom & Schutz, 1992). Aligned with the study's purpose, the counterattack-phase was divided into two subphases considering the natural and sequential game structure: (i) no-ball possession (defensive-organisation), leading to block and dig actions, (ii), ball-possession (offensive-organisation), comprising the set and attack actions. The opposition attacking context was reviewed for attacking options available to the setter. Thus, the opponents could be playing *in*-system (all hitters available) or *out*-system (only the outside-hitters and/or the opposite available) (adapted from Laporta et al., 2018)). The *full*-system combines both attacking contexts (i.e., playing *in*- and *out*-system).

Recording Procedures

Three matches were selected based on the following criteria: competitive moment (i.e., matches from regional and national competitions were included), opposition level (i.e., only matches against the top four ranked teams in the previous competitive season were selected), and number of counterattacking practice tasks undertaken in training (i.e., only included matches from which at least 6 counterattack practice tasks were performed during training in the previous week). The defensive-subphase was defined from the instant when opponents performed the first ball-contact to the third ball-contact. The offensive-subphase was defined from the instant that the evaluated team performed the first ball-contact to the third ball-contact. Overall, 48 (16 per-match) and 24 (8 per-match) sequences were analysed with opponents playing in *full*- and *in*-system, respectively. Occasionally, the number of counterattacking sequences of the match was greater than the number of sequences selected. Here, the sequences scored using attacking actions were privileged, as they required an intense and challenging cooperative dynamic between teammates.

Matches were performed on volleyball courts measuring 18m x 9m (width x length). Video recordings were captured using a camera positioned above (2m) and behind (5m) the court. The camera zooming rate was fixed to simplify image treatment. Images were recorded at a 25 Hz frequency and a resolution of 1920 x 1080 pixels. Calibration points were located on the ends of the court (two points) on the lateral 3m line (two points), and over each antenna (two points) (Duarte et al., 2010). Players' positional coordinates were recorded using TACTO software (version 8.0) with an accuracy level higher than 95% at 25 Hz (Fernandes, Folgado, Duarte, & Malta, 2010). In this procedure the players' working point was tracked (projection of gravity centre locating the mean distance between players' feet) using a computer mouse in slow-motion video. This software afforded players' 2D virtual coordinates (expressed in pixels). The Direct Linear Transformation method ensured conversion from virtual to real coordinates (expressed in meters) (Duarte et al., 2010).

Reliability

Five sequences were randomly selected, with players' data trajectories being re-digitised by the same author. Data reliability and accuracy were checked through the percentage of technical error of measurement (%TEM) and coefficient of reliability (R) (Goto & Mascie-Taylor, 2007). Intra-observer results demonstrated good accuracy and reliability levels (%TEM = 2.7, R > 0.9, respectively).

Cluster-Phase Method (CPM)

The CPM allowed us to compute the means and continuous group synchrony levels, ρ_{group} and $\rho_{group}(t_i)$, and player's relative phase, θ_k (Richardson, Garcia, Frank, Gergor, & Marsh, 2012). This method was recently used by Ribeiro et al. (2019) to assess emergent synchronisation tendencies at a meso-scale level through multilevel-hypernetworks in teams. Here, we adapted the expressions used by Ribeiro and colleagues to calculate the cluster-phase i.e., cluster-amplitude values, and to capture the team ST in each time-series. The ST refer to the coordination patterns developed by players through their interactions over time that allow them to temporarily form functional synergies in each counterattack-subphase. Specifically, we replaced the simplice sets Γ_j, by the set of players composing team Γ_A. Therefore, Γ_A and its size n_A, is defined by the number of players that compose Team A. The expressions used are described below, from (1) to (4).

Given the phase time-series obtained through Hilbert transformation, $\theta_k(t_i)$, for the k^{th} player movements measured in radians [-π π], where $k = 1, \cdots, N$ and $i = 1, \cdots, T$ time steps, the Team A or *cluster* phase time-series, $\overline{\emptyset}_A(t_i)$, can be calculated as:

$\acute{r}_A(t_i)\frac{1}{n_A}\sum_{k\in\Gamma_A}\exp(i\theta_k(t_i))$..(1)

and:

$\overline{\emptyset}_A(t_i)\ atan2(\acute{r}_A(t_i))$..(2)

where $i = \sqrt{-1}$ (when not used as a time step index), $\acute{r}_j(t_i)$ and $\overline{\emptyset}_j(t_i)$ comprise the resulting cluster phase in complex and radian form, respectively. Ultimately, the continuous degree of synchronisation of Team A $\boldsymbol{\rho_{\Gamma_A}(t_i)} \in [\mathbf{0},\mathbf{1}]$, i.e., the cluster amplitude $\boldsymbol{\rho_{\Gamma_A}(t_i)}$ at each time step t_i can be computed as:

$\rho_{\Gamma_A}(t_i) = \left|\frac{1}{\mathrm{n}_A}\sum_{k\in\Gamma_A}\exp\left(i(\theta_k(t_i)\ \overline{\emptyset}_A(t_i))\right)\right|$..(3)

and the temporal mean degree of group synchronisation, $\boldsymbol{\rho_{\Gamma_A}} \in [\mathbf{0},\mathbf{1}]$, is computed as:

$\rho_{\Gamma_A}\frac{1}{T}\sum_{i=1}^{T}\rho_{\Gamma_A}(t_i)$...(4)

Summarising, the Hilbert transform of each sequence of values for the longitudinal and lateral players' coordinates was calculated for each time frame of the match, obtaining each player's phase value. Next, we measured the cluster-phase (i.e., team's phase value) by summing all of each player's phase values. Afterwards, we computed the differences of each player's phase values with respect to the cluster-phase, and calculated the mean of those differences, finding the cluster-amplitude mean value. The cluster amplitude value corresponds to the inverse of the circular variance of $\emptyset k(ti)$. Therefore, if $\rho\Gamma_A$ = 1, the team is totally synchronised, and if $\rho\Gamma_A$ = 0, the team is completely unsynchronised. The cluster-amplitude values were computed through specific routines implemented in GNU OCTAVE (version 5.1.0).

Data Analysis

A 3 (matches) x 2 (counterattack-subphases) x 2 (opposition attacking contexts) x 2 (court directions) repeated-measures ANOVA was used to calculate differences in cluster-amplitude mean values between matches, as a function of counterattack-subphases (defensive and offensive), opposition attacking contexts (*full*-system and *in*-system) and court directions (lateral and longitudinal). Given the equality in group sample sizes, the homogeneity of variances was assumed (Field, 2009). Violations of sphericity assumption for the within–participant variables were checked using Mauchly's test. The Greenhouse-Geisser correction procedure was used to adjust the dofs. Pairwise differences were evaluated through Bonferroni post-hoc. Statistical significance level was set at $p = 0.05$. Effect size values were interpreted by partial eta-squared (η_p^2) (Levine & Hullett, 2002), as small ($\eta_p^2 < 0.06$), moderate ($0.06 \leq \eta_p^2 < 0.15$) or large ($\eta_p^2 \geq 0.15$) (Cohen, 1988). Inter-match differences were calculated through standardised mean differences (SMD), via Cohen's *d*, with 95% confidence intervals. Inferential statistical procedures were conducted using SPSS 25.0 software (IBM, Inc., Chicago, IL).

Results

Table 3 summarises the mean and standard deviation values of the team's cluster-amplitude in each AR-cycle as a function of counterattack-subphases, opposition attacking contexts and court directions. Figure 1 portrays the inter-standardised mean differences among matches.

Table 3. Mean and standard deviation of cluster-amplitude values during each AR-cycle as function of counterattacking-subphases (defensive and offensive), opposition attacking contexts (*full*-system and *in*-system) and court directions (lateral and longitudinal)

	1st AR-cycle Match 1 (M1)		2nd AR-cycle Match 2 (M2)		3rd AR-cycle Match 3 (M3)	
Defensive subphase (no-ball possession)						
Opponents' playing in ***full*-system**						
Court Direction	Lat	Long	Lat	Long	Lat	Long
Mean ± SD	0.82 ± 0.27	0.85 ± 0.24	0.83 ± 0.22	0.83 ± 0.22	0.87 ± 0.21	0.87 ± 0.20
Opponents' playing ***in*-system**						
	0.70 ± 0.30	0.82 ± 0.25	0.71 ± 0.29	0.73 ± 0.3	0.85 ± 0.21	0.90 ± 0.18
Offensive subphase (ball possession)						
Opponents' playing in ***full*-system**						
	0.85 ± 0.25	0.86 ± 0.24	0.80 ± 0.25	0.81 ± 0.23	0.87 ± 0.21	0.86 ± 0.22
Opponents' playing ***in*-system**						
	0.75 ± 0.27	0.78 ± 0.26	0.77 ± 0.27	0.78 ± 0.25	0.85 ± 0.24	0.84 ± 0.23

Note: SD = Standard Deviation; Lat = Lateral; Long = Longitudinal

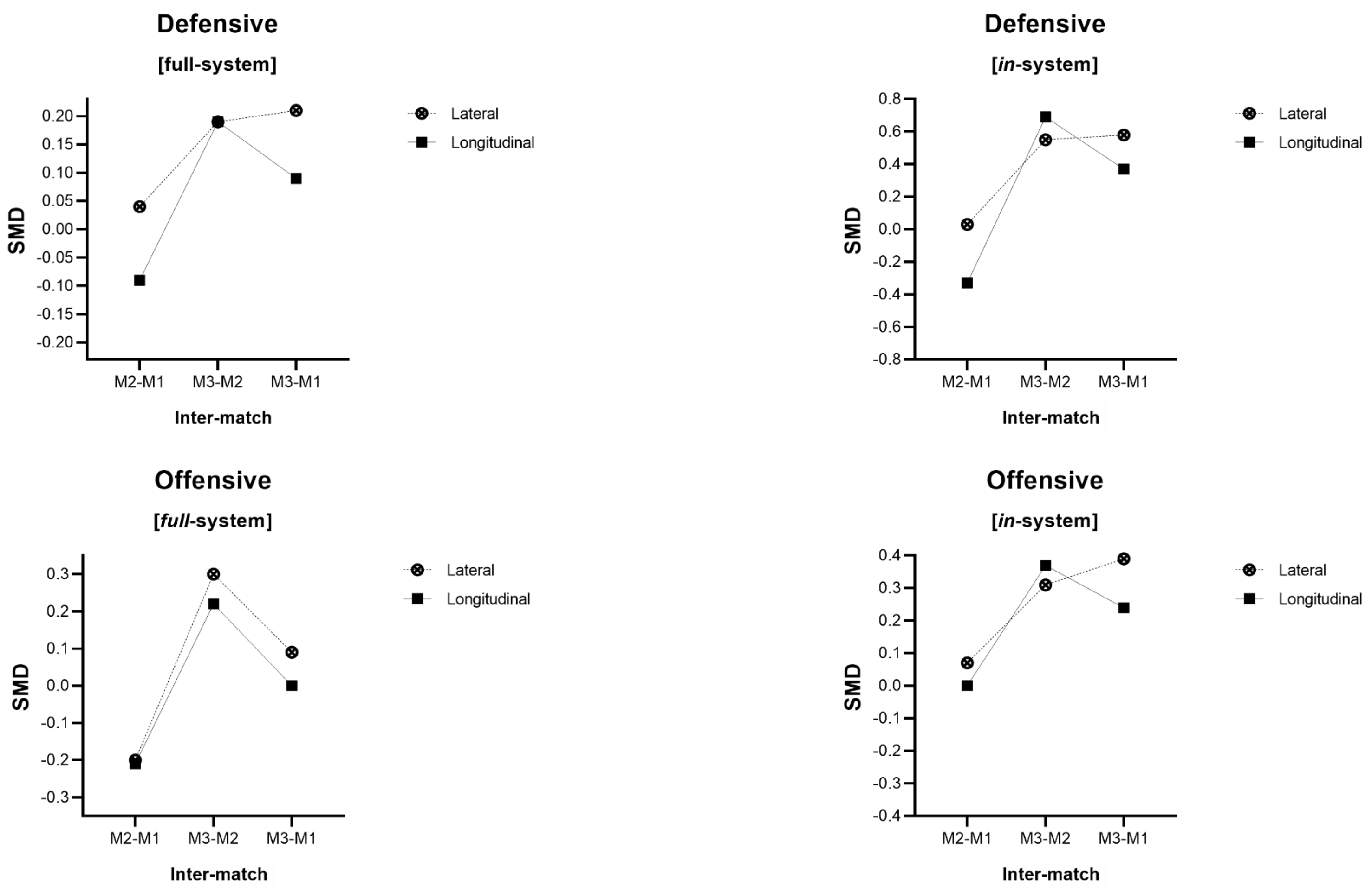


Figure 1. Standardised mean differences for inter-match synchronisation tendencies of the team (via cluster-amplitude values) throughout the competitive season as function of counterattack-subphase, opposition attacking contexts and court directions.

Defensive subphase (no-ball possession)

The inter-match analysis when opponents were playing in *full*-system, revealed small significant differences for ST in lateral ($F_{(2,000)}$=188,174; p<0.001, η_p^2 = 0.03) and longitudinal ($F_{(2,000)}$=135,996; p<0.001, η_p^2 = 0.02) court directions. Significant differences in lateral ST were observed between all matches (p<0.001), with the lowest and the highest values being attained at M1 and M3, respectively. Similarly, we observed significant differences in longitudinal ST between all matches (p<0.001), with the lowest and the highest synchronisation values being verified at M2 and M3, respectively.

The inter-match analysis when opponents were playing *in*-system, revealed significant differences for ST in lateral ($F_{(2,000)}$=451,974; p<0.001, η_p^2 =0.2) and longitudinal ($F_{(2,000)}$=455,146; p<0.001, η_p^2 = 0.2) directions. Significant differences (p<0.001) for lateral ST were found between M3-M1 and M3-M2, with no statistical differences between M2-M1 (p=0.410). The lowest and the highest values for lateral ST were verified during the first and third match, respectively. Significant differences (p<0.001) for longitudinal ST were found between all matches, with the lowest synchronisation value being observed during M2, and the highest value in M3.

Offensive subphase (ball possession)

The inter-match analysis when opponents were playing in *full*-system, showed significant differences for ST in lateral ($F_{(2,000)}$=539,309; p<0.001, η_p^2 = 0.05) and longitudinal ($F_{(2,000)}$=314,071; p<0.001, η_p^2 = 0.03) court directions. Significant differences (p<0.001) for lateral ST were observed across all matches, with the lowest and highest synchronisation values being verified during the M2 and M3, respectively. Significant differences in longitudinal ST were found between M2-M1 and M3-M2 (p<0.001), with the lowest synchronisation value being observed during M2. No significant differences in longitudinal ST were observed between M3-M1 (p=1.000).

The inter-match analysis when opponents were playing *in*-system, revealed moderate and small significant differences for team ST in lateral ($F_{(2,000)}$=263,792; p<0.001, η_p^2 =0.08) and longitudinal ($F_{(2,000)}$=171,209; p<0.001,

η_p^2 =0.06) court directions. Significant differences ($p<0.001$) in lateral ST were found between all matches, with the lowest and highest synchronisation values being attained at M1 and M3, respectively. Significant differences ($p<0.001$) in longitudinal ST were observed between M1-M3 and M2-M3, with the highest value being observed during M3. No significant differences in longitudinal ST were attained between M2-M1 ($p=1.000$).

Discussion

Integrating ecological (CLA) and constructivist (SGA) approaches through an insider-AR implemented over a season, this study analysed the influence of increasing tactical complexity on collective ST in both counterattack-subphases. Additionally, we investigated how opposition attacking contexts impacted on the team ST at each counterattack-subphase. Overall, combining CLA-SGA principles seems to support the development of tactical coordinative structures. Results depicted that: (i) tactical complexity increments (2nd AR-cycle) were followed by decreases in ST, (ii) opposition attacking contexts progressively reduced their influence on team ST, (iii) the insider-AR ensured a close monitoring of training processes, providing contextualised insights about team's tactical needs which supported pedagogical interventions.

Throughout the 1st AR-cycle, diagnosis of the main co-adaptative weaknesses identified on team ST during the defensive-subphase (no-ball possession), mirrored by the lowest synchronisation values observed. This outcome suggested difficulties in players' picking up relevant information sources when they were playing without the ball, perhaps expressing attentional focus flaws. This idea corroborates the findings of McGuckian and colleagues (2020), who showed that footballers used fewer visual head movements without ball possession. The ability to identify and interpret key informational constraints in competition is particularly relevant in non-invasion sports, which given their nature, requires quick and continuous tactical adaptations. At this stage, the players' game-related knowledge of the environment and the use of tactics (Woods et al., 2020) was still at the beginning of its development, limiting the exploration of key opposition constraints.

To reverse this trend, from the 1st AR-cycle, practice tasks (i.e., based on specific skills performance) were ‘time-constrained’ to narrow players’ attentional focus. For instance, players started defending with eyes-closed to scan rapidly for relevant information when opened. During such tasks, the coach used convergent questioning (e.g., are you looking at the ball or attackers’ arm? Looking at the direction of the attackers’ arm may help to predict the ball trajectory after the strike) (Siedentop & Tannehill, 2000). This coaching intervention sought to simplify nested constraints (i.e., embedded in different timescales) inherent to competition, by isolating the key action opportunities (e.g., anticipate the dig action) (Balagué, Pol, Torrents, Ric, & Hristovski, 2019).

Possibly due to this coaching intervention, across the 2nd AR-cycle, we observed slight improvements in lateral ST at the defensive-subphase. To continue these improvements, didactical structuring tasks (i.e., focused on comprehending the tactical-technical skills within the competitive environment) evolved in terms of content complexity. To exemplify, playing against in-system context, the opposition setter was able to freely choose the attack zone. Thus, players were stimulated to intentionally looking for meaningful information from the opposition setter so that they could anticipate the attacking zone. Divergent questioning (e.g., where should you look? Why?) was included to enhance the players’ attention (e.g., when the setter contacts the ball close to herself, she only can set to zone 2).

To develop players’ co-adaptative skills, during the 2nd AR-cycle, the coach increased tactical complexity in both counterattack-subphases, through tactical step-by-step challenges (SGA) practically implemented using a Constraint-Led perspective. To exemplify, in offensive organization, fast tempos and attack combinations were introduced. Defensively, the number of defenders was reduced (i.e., a double-block organization implying fewer defenders covering more space). As hypothesised, increasing tactical complexity prompted a decrease in collective ST during the second match, particularly during the offensive-subphase. This finding supports the assumption of Balágue and colleagues (2013), namely that the team’s co-adaptative process could be affected by introduction of complexity, acting as system “noise”.

Interestingly, the highest team synchrony values emerged during the third match, suggesting a re-emergence of functional ST within more complex tactical patterns from relative spatial location of players (Gréhaigne & Godbout, 2014)). Therefore, the "noise" introduced seems have played a functional role, allowing the system to reach a "dynamic stability" (Passos, Araújo, & Davids, 2016). This finding supports the assumption of Hristovski et al. (2009), explicitly that *metastability* is crucial for players to co-adapt behaviours. The dynamics of a metastable region of performance landscape can be exploited, for instance, when players continuously transit among different stages of block-defence organization according to opposition attacking contexts. This aspect of practice design allowed the team to maintain functional performance integrity required to exploit tactical advantages within challenging competitive environments. Moreover, the highest ST observed over the 3rd AR-cycle underlines the importance of players being embedded within specific-didactical and representative practice programmes for long time-periods to improve their attunement to relevant informational constraints translated, in terms of performance, by the (re)emergence of ST.

As hypothesised, the influence of opposition attacking context on ST was progressively reduced. The strategical game-plan introduced, from the 2nd AR-cycle, might explain this finding. This strategy involved constructive discussions between players with the coach, who sought to stimulate the players' tactical understanding. Players were invited to interpret the opposition's strategy exploring possible strategies to gain tactical advantages during competition (e.g., establishing block-priorities). Afterwards, as proposed by Woods and colleagues (2020), the learning tasks were co-designed following the principles defined by the strategical game-plan (i.e., encompassing the same information offered by competition – representativeness (Pinder, Davids, Renshaw, & Araújo, 2011). For instance, adaptation tasks were rule-constrained according to opposition features of play with questioning being used to reinforce tactical understanding (e.g., Did you see the block open? So why did you dig there?).

A limitation of the study was that the TACTO software did not allow us to directly collect data on positional coordinates at a three-dimensional scale of analysis. Hence the ball coordinates were not included in the study. Since players co-adapt their positioning according to ball location it could add valuable information. Moreover, our analysis was focused on the “phase” of the ST. The trajectory of a dynamical system (e.g., volleyball team ST) consists of a combination of “phase” and “amplitude” data, meaning that a movement in a different direction and/or velocity, produced as a consequence of another player’s movement, cannot be quantified as a synchronised.

Conclusion

This study emphasised the benefits of integrating ecological and constructivist approaches to develop ST during defensive and offensive counterattacking-subphases. The data encourage coaches to design representative and specific-didactical learning environments, predicated on the team’s tactical needs and strategical ideas from a game-plan (framing player intentionality). Results supported the integration of complementary pedagogical approaches that enable development of team co-adaptative processes. Findings endorsed use of questioning strategies to narrow the players’ attentional focus in searching practice landscapes, stimulating perceptual attunement to relevant competitive performance constraints. Results suggested that complex tactical organisation cause reductions in collective coordinative structures, with the (re)attainment of functional synchrony made feasible by integrating CLA-SGA principles. Methodologically, the insider-AR provided contextualised insights for a coaching intervention focused on improving collective ST.

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Chapter IV: Concluding Remarks

4.1 General discussion of the main findings

The main aim of this thesis was to investigate the impact of combining ecological (CLA) and constructivist (SGA) approaches on the development of sport performance in youth female volleyball players over the period of one competitive season. Specifically, the objectives were to (i) outline why an interplay of information between performance in competition and performance preparation can be effective in enhancing the development of sport performance, and to propose from a methodological perspective, how it can be accomplished in future scientific research, (ii) review, compare and quantify prior findings on the synergetic properties of dimensional compression and reciprocal compensation in team sports, (iii) explore how combining CLA with SGA might aid as a useful framework for understanding how players' tactical knowledge, and how collective synchronisation tendencies can be enhanced in competitive performance, and (iv) examine the impact of environmental constraints (i.e., set moment and opposition attacking context) on team synchronisation tendencies (i.e., synergetic property of reciprocal compensation) in official matches. One critical research note, one systematic review with meta-analysis, and three empirical studies are presented to meet these objectives.

The critical research note highlights that scientific investigations have mostly neglected the informational interplay between data from performance *in* (i.e., product analysis) and *for* competition (i.e., process analysis). The conventional use of cross-sectional analyses and experimental designs, framed within a positivistic paradigm, is one possible explanation for this limitation in scientific research on performance analysis. Based on this limitation, it was argued that there is a need to use theoretical and practical insights from the interpretative paradigm, and several methodological considerations for future investigations were recommended. Next, a major finding of the systematic review and meta-analysis was the lack of performance analysis within competitive environments, and notably pertaining to the synergetic properties of dimensional compression and reciprocal compensation. Additionally, this qualitative and quantitative review helped characterised the current research trend in evaluating the effects of interventional protocols applied to invasive team sports.

Specifically, protocols usually included the manipulation of tasks constraints mismatched with players' technical-tactical needs and/or team's synergetic properties. Aligned with this, the review also emphasised the current dearth of research on the didactical application of constraints manipulation according to the nature of each sport (i.e., invasive vs. non-invasive sports). The identification of such research patterns thus confirmed that the analysis of performance in competition has not been aligned with the information from sport performance preparation. By doing so, the design, monitoring and examination of the pedagogical process within training context has been continuously decontextualized and/or neglected.

Based on the recommendations made in the critical research note, as well as guided by the findings of the systematic review with meta-analysis, the subsequent empirical manuscripts adopted an insider AR-design (i.e., the research assumed concomitantly the dual role of head-coach and researcher) implemented over one competitive volleyball season. This interventive design was adopted to address the aforementioned research trend; that is, the interplayed analysis of sport performance at training and competitive contexts. The collaborative, cyclical and interventionist nature of the AR-design provided continuous and contextualised data collection and analysis, as well as a self-reflection about coach praxis and team's needs which, in turn, helped to guide the coaching intervention as it progressed. In particular, the insider role of the coach-researcher offered a close and deep perspective about the *processes* underlying to the development of holistic sport performance. In total, the information retrieved from the training and competitive context resulted in one qualitative and two quantitative papers.

The analysis of the pedagogical process in training requires the identification and in-depth analysis of variables that suitably represent and inform about practice rather than the use of metrics that, despite providing an overview of final performance outcomes (i.e., the *end-product* perspective), do not inform on how and why performance evolved. Based on this rationale and recognising the importance of the didactical content of each sport, the three empirical papers evaluated the impact of combining ecological and constructivist approaches

(CLA-SGA). Specifically, the qualitative paper considered the players' tactical knowledge as an appropriate variable for informing on how the coaching-learning process is expressed as the acquisition of players' game-related knowledge. Additionally, to ensure the linkage between competitive performance preparation and the assessment of performance in competition, the two quantitative papers focused on evaluating how the synergetic property of reciprocal compensation, expressed by collective synchronisation tendencies, evolved in competition as function of (i) increments in tactical complexity, (ii) set moments, and (iii) opponents' attacking conditions.

The principal findings of these empirical studies will be discussed in an integrated fashion. Given the common application of three AR-cycles across studies, the discussion will be subdivided by AR-cycles so that the timeline of events can be ensured and appropriately considered. Practical applications for sport practitioners, suggestions for future investigations, limitations of the present research project, and a synopsis of the main findings are included at the end of this chapter.

1st AR cycle [September 2017 – December 2017]: How did we start? Exploring individual and collective weaknesses

Following the recommendation of Gilbourne e Richardson (2005), throughout the first AR-cycle the coach-researcher identified the players' tactical weaknesses. Overall, at this initial stage players exhibited a lack of tactical understanding (i.e., the ability to identify different pieces of information, linking the tactical purpose of the learning tasks with the official game-form (McPherson, 2008)). Specifically, players were able to describe different tactical scenarios (i.e., knowledge *about* the performance environment), but were not able to actively identify, share or anticipate action opportunities (knowledge *of* the environment).

From a macro-level of analysis, the high lateral and longitudinal values (0.87 and 0.86, respectively) portrayed on the collective synchronisation tendencies during the global counterattack-phase did not seem to be congruent with the sparse tactical knowledge initially observed. Indeed, if one was only considering this macro-analysis, it would appear that this finding contradicts the studies of Silva et al. (2013) and Araújo e Davids (2016). The authors argued that during competitive performance the control of players' actions are predicted by knowledge *of* the environment, which supports the share of affordances as the main communication channel to coordinate collective behaviours. However, after extending the analysis to a meso-level, that is, decomposing the counterattack-phase into defensive (no ball-possession) and offensive (ball-possession) subphases, the analyses revealed reductions in team synchronisation at the defensive subphase (Lat: 0.82; Long: 0.85), with this tendency being substantial when opponents were playing with *in*-system attacking conditions (Lat: 0.70; Long: 0.82).

The integration of these findings suggests that despite the initial tactical model for the counterattack-phase having comprised a simplistic defensive organisation (i.e., single-blocker with the remaining five players filling the middle of the court), players showed limitations in their ability to focus attention on the most critical information sources (e.g., opponents' attacking context). This finding addresses the importance of players exploiting both *local-to-global* and *global-to-local* tactical attentional focus, as endorsed by Ribeiro and colleagues (2019). This deficit was particularly notable in the defensive-subphase when opponents were attacking *in*-system, possibly because the opponents have possession with all the hitters available, which for the defending players requires a strong ability to quickly pick up and interpret the critical information of the competitive game scenario. This finding is consistent with the recent results of McGuckian et al. (2018), who found a significant reduction in football players' head movements when playing without ball possession (defending subphase).

The close monitoring of this tactical issue afforded by the insider-AR design, meant that from the first AR-cycle that acquisition tasks were didactically constrained so that players could learn to redirect their attentional focus (Mesquita et al., 2005). For example, and as reported, players started defending with their eyes closed (task constraint) so that they could rapidly search for relevant information (e.g., opponents' arm direction) when opened. The performance of such tasks was initially accompanied by convergent questions (i.e., questions that require less knowledge and ability from players, who are invited to provided simple and oriented response; e.g., Are you looking at the ball or the setter?) (Metzler, 2011). Thus, by decomposing the game scenarios into representative and less complex learning tasks, didactically conceived and constrained through the combined application of ecological (CLA) and didactical principles (SGA), the coach intended to simplify the nested constraints (i.e., entrenched at different time-scales) as reinforced by Balagué et al. (2019). By doing so, players started to narrow their attentional focus on the relevant didactical-specific constraints. This idea is coherent with the previous findings of Memmert e Furley (2007), who found that more tactical instructions can lead to a narrower breadth of attention.

Concerning the influence of final set moments, although the teams' global synchronisation tendencies were high (Lat: 0.88; Long: 0.88), the contrast with the qualitative results indicates that such cooperative and co-adaptative processes were quite invariable offensively, leading to predictable and not tactically contextualised behaviours. This is confirmed by the excerpt:

"Researcher (R): Kate, do you feel that your setting options changed after 20 points?
Kate: I cannot vary the game, I only set to the player who I know is going to score more."

2nd AR cycle [January 2018 – March 2018]: Has the increasing of tactical complexity had the same impact on players' tactical knowledge and collective synchronisation tendencies?

To provide players with different and more challenging stimuli and encourage problem-solving and tactical intentionality, throughout the second AR-cycle the tactical complexity of both game modelling and learning tasks were increased via the manipulation of didactical tasks constraints (i.e., combining CLA with SGA principles). Specifically, double-blocks were encouraged at the defensive-subphase, meaning that the number of defenders covering the space on the court was reduced. Simultaneously, fast attacking tempos and attack combinations (i.e., players attacking in several zones, including the crossing of sectors) were preferred at the offensive-subphase. Interestingly, this increase of tactical complexity had distinct repercussions on players' tactical knowledge and collective synchronisation processes.

Players reported enhancements in their tactical awareness, attentional focus, tactical understanding, and strategical thinking as tactical complexity increased. Indeed, as stated by Katherine:

"*once the game became more complex we needed to stay focused, think more and this ends up affecting us […] for instance, during the attack, now I can see the block but, in the past, I only did what the coach told to me, without thinking about it".*

This finding is consistent with the results of Shaw et al. (2018), who showed how increasing task demands led to an augmented engagement and consumption of attentional resources. However, contrary to this positive evolution of players' TK, the macro- and meso-analysis of collective synchronisation tendencies in competition displayed significant reductions as the tactical complexity increased (Macro-level - Lat: 0.81; Long: 0.81; Meso-level – Lat: 0.83; Long: 0.83). This result corroborates the assumption of Balagué et al. (2013) that the self-organisation tendencies of a system (i.e., team) can be affected by the introduction of "noise" (in this case, higher complexity organization of the game-modelling). Moreover, this finding is also in line with the findings of Faure and colleagues (2019), that team coordination levels depend on task complexity (namely, the uncertainty on teammate's action and visual information perceived).

Moreover, this finding also suggests that while the players had developed their *knowledge of* the environment (i.e., game-related knowledge, that is, acquiring perceptual information to directly shape functional behaviours; e.g., understanding the flight of the ball in a space-time trajectory, connecting it with opponents' movements in preparing an action), the practical application of this game-related knowledge in competition was not immediate. In other words, it seems have existed a delay between the tactical knowledge acquired by players and its practical use within competitive environments. This finding corroborates the investigation of Araújo et al. (2018), who stated that a continuous exposure to meaningful and representative practices is required so that the gains in terms of the cognitive domain (i.e., active construction of game-related knowledge) can be translated into practice as functional team synergies (i.e., synchronisation tendencies).

The AR-design format adopted meant that the coach-researcher was aware of the improvements in players' TK, as well as their difficulties in cooperating synergistically within more complex game models. At this stage, the coaching intervention advocated the design of sophisticated structuring tasks, manipulated in terms of game-rules (e.g., number of setting options). Specifically, through the combined used of CLA and SGA principles, ecological game scenarios were didactically conceived to improve counterattack organization when opponents were playing with *in*-system attacking conditions. Thus, with this ecological-didactical coaching intervention, players were invited to intentionally search for meaningful opponents' clues (i.e., informational constraints), anticipate their actions and extend their comprehension about the application of technical-tactical skills in competition (Davids et al., 2008; Mesquita et al., 2005).

Additionally, divergent questions (i.e., questions that entail multiple answers, encompassing a careful and logical structure of information) started to be used to help focus the players' attention (Metzler, 2011). Possibly due to the pedagogical strategies adopted, while opponents were playing *in*-system the lateral synchronisation values during the defensive counterattack-subphase remained relatively high. In other words, even playing within a more complex game-form, and against the most challenging game-scenarios, the coaching strategies adopted, aligned with the enhancements of players' TK, may have helped the team to partially co-adapt their tactical tendencies. The benefit observed from using divergent questioning strategies was consistent with the findings of Broek et al. (2011), which showed players submitted to tactical questioning strategies significantly improved their the tactical knowledge compared to players involved in coach-centred instructional groups and athletes-centred groups without tactical questioning.

The analysis of collective coordination patterns as function of set moments revealed slight increases at the initial set moments. Supported by the qualitative evidence, such improvement seems to be explained by the introduction and co-

construction of a basic strategical game-plan framed upon video analysis. Indeed, as claimed by Rose:

"*In almost all matches this* [game plan] *helps us, because during the game we know exactly what the weaknesses of the opponent are and where we should attack"*.

Specifically, this coaching strategy involved a constructive debate among the coach and players about the next opponent's features (e.g., identifying the best hitter) and tactical patterns (i.e., recognising the defensive block organisation), with both parties mutually defining the best configurations of play[7] that should be adopted to gain tactical advantage during the upcoming match. This player-coach analysis, conducted mostly using video feedback, has been highlighted as extremely beneficial by Moreno et al. (2016). The acknowledgement of these simple, but critical, informational constraints seems to guide players progressively towards a functional and reciprocal interplay during the initial moments of the set, in which the mental fatigue is lower than at final set moments. This finding is aligned with the assumptions of Coutinho et al. (2017), that mental fatigue disturbs the players' ability to use environmental information.

Congruently, the team synchronisation tendencies decreased in final set moments, reinforcing the idea that this particular phase of the set is an important environmental constraint specific to volleyball (Marcelino et al., 2011; Marcelino et al., 2012; Ramos et al., 2017). To call the players' attentional focus to this environmental constraint, during the training sessions the coach frequently assumed an active and interventive position, using divergent questioning strategies to strengthen the notion of using an intentional, goal- and action-oriented sense of strategy in competitive game tasks (i.e., use of tactics in-game). The following excerpt retrieved from coach's reflexive diary, and shared in the qualitative paper, clearly exemplifies this process:

"When we were training final set moments, that is, a game phase that highlights tactical awareness, Emily failed three consecutive setting options, and I just screamed EMILY!!! She came to me and said that she knew that she should not have set the ball to Jennifer.

[7] The schema drawn from the relative spatial location of players according to the specific instructions received during training sessions (Gréhaigne & Godbout, 2014).

I asked her why, and she responded that as she had good setting conditions and had Mariah and Kate in attack positions, she should set to one of them."

3rd AR cycle [April 2018 – June 2018] – Adaptable tactical knowledge as a precursor to functional and complexified collective synchronisations tendencies

At the end of the third AR-cycle it was noteworthy that there was a substantial enhancement in players' TK. Indeed, the integrative use of CLA and SGA assumptions – that is, extended practice using representative, didactical and meaningful learning designs – afforded the development of knowledge *of* the environment. As such, at the end of the competitive sport season, players were endowed with collaborative and self-organised skills that allow them to effectively anticipate opponents' moves. The linkage of this result with evidence from the macro- and meso-analysis of the team's synchrony revealed that, in practical terms, the enhancements in players' TK were expressed by the (re)achievement of high values of collective synchronisation tendencies. In fact, even playing within a more complex tactical model, the team's synchrony values were similar to, and in many cases greater than, those observed at the beginning of the competitive season. Moreover, similar global values of the team synchronisation tendencies were observed at the defensive and offensive counterattack-subphases when playing against *in*-system attacking conditions, meaning that even playing against the most challenging tactical situations players were able to rapidly identify and interpret the most critical information, anticipate the opponents' moves, and act synergistically. Overall, this outcome portrays three major implications.

First, as stated above, this finding underlines the need for long-term practice to develop players' tactical awareness, as well as the need to apply such knowledge in collective dynamical practice. Indeed, the sharing of affordances (*for* and *of* others) that predict the formation of team synergies, implies a preliminary identification and common interpretation of the constraints and action opportunities in competitive environments (Araújo & Davids, 2016; Silva et al., 2016). In this respect, as stated by Silva et al. (2013), the collective action opportunities can only be perceived if players train to become perceptually attuned to them. Based on this idea, by combining CLA-SGA pedagogical principles the coach-researcher monitored and designed daily learning tasks that were congruent with players' tactical needs and the demands of the next official match. Consequently, this ecological and didactical practice helped to establish both a congruent link between training and competition stimuli and a continual attunement to affordances *for* and *of* others during competition, which was expressed by the coherent and efficient formation of functional coordinated structures by the end of the season. This pedagogical intervention aligns with Woods and colleagues' (2019) recommendations to use principles of ecological dynamics along with data from competitive performance to understand competitive demands according to each sport.

Second, this finding suggests that game-related knowledge and the strategical thinking form a useful and immeasurable basis to the self-organisation process, as well as the adoption of co-adaptive behaviours in competition. Thus, by recognising the importance of an active and individual construction of knowledge (i.e., constructivist paradigm) and the dynamic and interactive relationship between individuals and their environments (ecological paradigm), the combined use of both paradigms is shown to be pertinent and highly necessary, as expressed in the following excerpt:

"R: […] reading the game … what do you mean?

Katherine: For instance, when someone is attacking, and we are defending … now we look to their arm and we anticipate the attack trajectory.

R: Did you think about it initially?

Katherine: I did not look so much, and if I looked, I couldn't understand it. Now, we also see the block and the setter, the setter cannot trick me anymore."

The combined use of ecological and constructivist approaches has been suggested in prior works (e.g., Clemente et al., 2012; Tan et al., 2012). The present research project not only answers this scientific call but goes further by incorporating the didactical content of a non-invasive sport, like volleyball.

Third, an in-depth and contextualised analysis of the pedagogical process underlying the holistic development of players sport performance could not have been achieved if an insider AR-design had not been adopted. Indeed, the immersion of the coach-researcher in the players' daily practice provided a unique standpoint that enabled a close and ongoing monitoring of the impact of combining CLA-SGA on players' tactical knowledge and team synchronisation tendencies. In fact, given the cyclical and interventive nature of an insider-AR, which highlights the intentional manipulation of task-individual-environment constraints, the interplay among data from performance *in* and *for* competition was guaranteed, as exemplified by the design of representative learning tasks in accordance with the strategical game-plan defined.

The gradual introduction and implementation of a more sophisticated game-plan seems to have largely contributed to the appropriate use of tactics in competition throughout all match periods and playing against any opponents' attacking conditions, as shown by the high value of synchronisation tendencies. Exemplifying the combined use of CLA and SGA principles, at this phase of the season the game-plan involved the definition of block-defence priorities per players' rotation at different set moments, enabling players to "*understand the opponents' weak features and to know how to exploit it",* as noted by Ellen. Afterwards, as recommended by Pinder et al. (2011), Travassos et al. (2012), and more recently Woods et al. (2021), ecological and representative adaptation tasks (i.e., where specific tactical issues were emphasized in a game-situation, encompassing the same perceptual-motor stimulus required in competition) were designed. For instance, thematic-games were constrained in terms of rules (e.g., setting and attacking options), accountability criteria (e.g., feeding with extra points double or triple block organization), and environmental scenarios (e.g., match-score, with the set starting on 20-20 points).

Accordingly, the ongoing exposure to this constructivist-ecological practice, together with the development of players' TK, seems to explain the reduction of influence that the set moment had on the team's synchrony formation. In other words, when players were tactically aware of the *which-how-when* to accomplish the most efficient *player-player* and *player-environment* interactions, they could ensure the functional integrity of the team, even when playing in critical and challenging game moments and/or conditions (i.e., final set moments, and *in*-system attacking conditions). The following qualitative evidence supports this assumption:

"Kate: I think we started to understand the game moments better. For example, at 24/24 we will set to a player that is displaying higher consistency across the game.
Emily: Yes, at the beginning I only set to Mariah, now I vary the game, for example, if she fails, I know that I cannot set to her again, immediately […] I always look for the opponent blockers', for instance, if Liz is in zone 2, I play a stick with middle-blocker"

Finally, it is worthwhile highlighting that the long-tracking of sport performance development suggested that the *noise* (i.e., increasing complexity of tactical play configurations) introduced in the system promoted a desirable instability that enabled the system to transition among multiple stable states (i.e., metastability) according to the competitive constraints (e.g., adopting simple, double or triple block-defence organisation interacting with opposition attacking contexts) (Passos et al., 2016). This finding is aligned with the well-established works of Kelso (2008) and Hristovski et al. (2009), which identified metastability as an important characteristic observed in complex systems, such as team sports. Through meta-stability, varied and creative patterns of behaviour can emerge when individual system components co-adapt to transit to other stable organisational states, ensuring the system's functionality.

4.2. Practical Applications for Sport Practitioners

Given the research design adopted, and the results obtained, the present thesis offers several practical guidelines for sport practitioners (coaches, performance analysts, teachers, etc.). Firstly, the research project championed the combined application of distinct, yet complementary, approaches (CLA and SGA) for the planning, structuring, designing and monitoring of training sessions and sports performance enhancement. Indeed, because the practical context (i.e., *praxis*) is always more complex and challenging than the theoretical rationale due to the unlimited and multifactorial relationships among individuals and their environment, the art of coaching is placed on balancing the best pedagogical principles and strategies to satisfy the players' and/or team's needs at any particular moment. Therefore, coaches need to develop the extremely powerful and important skills of being sensitive and aware of current players' needs according to competitive demands, as well as being able to read and analyse both the bigger picture and smallest details, to successfully orchestrate their teams.

Supported by our findings, we propose that coaches should design learnings tasks constrained according to: (i) the technical-tactical requirements of both players and the team, (ii) the nature (invasive and non-invasive games), the didactical specificities, and the competitive features/demands of each sport, and (iii) the tactical features of the next opponent team. Additionally, we strongly advise that coaches focus on adopting didactical-specific and representative learning designs founded on the co-constructive building of a strategic game-plan. In this respect, video analysis can play an important role in defining strategical principles so that a tactical advantage during the upcoming match can be obtained. In doing so, the training session will naturally be meaningful for players, while at the same time competitive data will support the performance preparation. To exemplify, assuming that the analysis of a match-report and the collective synchronisation tendencies reveal low blocking dynamics, the subsequent training session could focus on the blocking action as follows: (i) acquisition-tasks, with players individually executing the block action technique as a function of different attacking tempos (task constraint in terms of 'time'); (ii) structuring tasks, with players blocking as a function of the opponent setter's tactical decision (task constraint in terms of 'time' and 'space', which integrates blocking technique into a tactical game scenarios); and, (iii) adaptation tasks, full game-forms with the block action reward with double scored blocking points (task constraint in terms of 'game rule') – narrowing the application of time-space technique into a tactical, multivariable and unpredictable environment – representative of the competitive context. Regarding the coach intervention throughout these tasks, we propose that he/she use questioning strategies to address the most technical and tactical issues that required improvement.

Indeed, the findings indicate that the use of convergent and divergent questioning can stimulate the development of players' critical thinking and the narrowing of players' attentional focus. Moreover, by using effective questioning, coaches can prevent the prescription of resolutions that ends up in the development of proficient motor reproducers, but elementary thinkers. In this sense, we still encourage the development of players' tactical knowledge as a basis for the acquisition of co-adaptative behaviours during competitive performance. However, we also advise coaches that the development of players' TK does is nonlinear; that is, the acquisition of knowledge is not directly translated into practical terms. Truthfully, an implication of these findings is that there is a relatively wide delay between the achievement of game-related knowledge and its tactical application in competitive contexts.

Lastly, we strongly recommend that coaches working with youth players focus on creating healthy and rich pedagogical *processes* and contexts of learning (i.e., how players/the team plays), rather than be concerned with performance outcomes (i.e., if players/the team wins or loses). By understanding that individual and collective achievement is a natural consequence of a meaningful and powerful coaching-learning process, coaches are not only contributing to the development of active, critical and competitive adults, but also participating in the development of good human beings endowed with specific sports values (e.g., resilience, cooperation, hard-working), as nowadays is requested by our society.

4.3. Futures avenues for research

As stated at the start of this thesis, there is a need for investigations seeking to examine and explain sport performance phenomena in depth. To meet this objective, it is crucial that future investigations adopt interpretative methodological designs. Thus, as stated in the critical research note, we encourage the application of AR-designs in which qualitative and/or quantitative data are collected and examined. Given its features, AR interventions can provide contextualised insights about the intentional interventions of the sport agents (in this case, the head-coach intervention).

Without disregarding the interpretative paradigm, from a data analysis and statistical procedures viewpoint we also recommend the combined use of non-linear metrics with traditional linear statistics. In fact, by combining both metrics the analysis of the dynamical *player-player* and *player-environment* interactions is ensured, and the information retrieved is easily interpreted and understood by coaches and sport practitioners, reducing the gap between theory and practice. For example, this methodological approach was recently used by Ribeiro et al. (2020), with the authors combining the cluster-phase method and sample entropy values (non-linear metrics) with univariate ANOVA to ascertain the cluster amplitude mean values between game conditions, and as a function of ball possession, field direction, and teams. Furthermore, considering the publication bias identified in the meta-analysis, we strongly recommend methodological care in future investigation dedicated to examining key synergetic properties, and particularly those of dimensional compression and reciprocal compensation. In this sense, the reporting of non-significant effects and the detailed sharing of the full statistical procedures used in investigations are equally recommended.

Additionally, due to the complex relationships between perception, action, and cognition that are inherent to the enhancement of players' performance, we suggest that future investigations continue to integrate complementary teaching approaches that acknowledge the unpredictable and complex nature of sport practice. For instance, considering the specific nature of invasive sports games, the CLA could also be combined with the Invasion-Games Competence Model (Musch et al., 2002). The analysis of different samples (e.g., male and/or older players) and contexts (e.g., expert players) should also be explored in future investigations. Specifically, the scrutiny of other sports within high-level contexts would be important to ascertain and align the pedagogical requirements about sport performance development from youth to senior training levels. Such analysis could even be used to identify possible pathways to success and enrich talent identification programmes.

Concerning volleyball analysis, we suggest that future studies consider team synchronisation tendencies as a valuable indicator for assessing and monitoring the process underlying tactical performance enhancements. Here, team synchrony could be analysed at a micro-scale by exploring the coordinative process of dyads (i.e., sub-systems of two players within a system). For instance, the analysis of synchronisation tendencies between the middle-blocker and the defender at zone 6 could be helpful for investigating the core of the defensive and offensive tactical organization because both players interact in the same sector of the court. Moreover, the analysis of team synchronisation tendencies could be explored across distinct game-complexes, such as side-out (complex-I), attack-coverage (complex-IV), and freeball (complex-V). To optimise the collection, treatment, and analysis of data we also suggest that future studies explore the development of a smart application or software that, during the competition (i.e., live), can inform the coach about the synergetic properties of his/her team.

4.4. Limitations

The work presented in this thesis has some methodological limitations that should be acknowledge. Firstly, due to limitations of the TACTO software, namely the inability to directly record ball coordinates in three-dimensions (x, y, z), the research team decided not to integrate the ball coordinates in any of the empirical quantitative studies. Once the players moved according to the ball position, especially in non-invasive games, the inclusion of the ball's coordinates could bring valuable information to future research. Secondly, the routines applied consider globally the "phase" synchronisation of the dynamical system (i.e., volleyball team) as a combination of "phase" and "amplitude", meaning that a different direction, with more or less velocity, produced in reaction to an opponent's behaviour, is not quantified as a synchronised behaviour. Thirdly, considering the interplay of qualitative information between players' tactical knowledge and other dimensions, such as players' decision-making, autonomy and/or team cohesion, could broaden current understanding about the benefits of applying a CLA-SGA coaching intervention.

4.5. Synopsis of the main findings

Given the main findings of the individual studies presented in this thesis, the following general conclusions can be highlighted:

- The combined application of two distinct approaches, CLA-SGA, (i.e., the integration of ecological and constructivist ideas) appears to be a useful framework for enhancing players' tactical knowledge and team synchronisation tendencies in competition.

- The increase of tactical complexity in playing configurations acted as *noise* to the system (i.e., team), promoting a desirable instability that led to transitions among stable states (metastability), and thus reinforcing the self-organization and adaptative skills of the team. At the same time, such growth of complexity led to improvements in players' tactical awareness, attentional focus, and strategic thinking.
- The final moment of the set and the *in*-system attacking conditions of opponents were found to be critical environmental constraints, specific to volleyball, that progressively reduced in influence as a response to the combined application of CLA and SGA principles. Specifically, when players' tactical knowledge enhanced a reduction in these constraints was observed.
- The cluster-phase method proved to be useful for assessing the synergetic property of reciprocal compensation in a non-invasive team sport.
- The innovative application of an insider AR-design for the duration of a competitive season afforded a deep, contextualized, and close analysis of the coaching-learning process.
- By simultaneously acting as a *learning facilitator* and *learning designer*, the coach-researcher was able to actively scaffold the holistic development of players' sport performance.
- The co-construction and acquisition of tactical knowledge was found to be a basis for the achievement of functional synchronisation tendencies in competition. It was noteworthy, however, that this relationship was not linear. Accordingly, a major finding was that it was necessary to continuously expose players to meaningful and representative practice (here represented by the integration of constraint-led and step-game approaches) so that they could translate game-related knowledge into competitive practice.
- The cooperative (i.e., coach and players) construction of a game-plan, aligned with questioning strategies and the design of specific-didactical

and representative learning tasks, was found to be an appropriate catalyst for the identification of constraints and exploration of affordances in the competitive environment.

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Supplements

Supplement 1. Main instructional principles considered in each pedagogical approach

Constraints-led Approach	Step-Game Approach
Constraints Manipulation - to guide players' attentional focus, create a desirable instability in learning processes, and encourage the problem-solving of a specific tactical/technical issue within multiple training scenarios	***Cue interpretation*** – players are invited to develop the experience of identifying and interpreting appropriate technical and tactical cues within a wide variety of learning scenarios
Design of action opportunities (affordances) – creation of opportunities that allow players to construct for themselves the 'how, why, where, when' to perform an action	***Questioning*** – players are continuously questioned about tactical aspects so that they can explore and construct their own solution
Evolving co-adaptation processes – reinforce the cooperation between teammates, who must self-organise to satisfy the interacting task demands and accomplish the task goals	***Strategic plan*** – main principles of play defined to the next official competition. Such principles are collectively and constructively discussed between coach and players at the beginning of the week so that they can guide the subsequent training plans. This process encompasses an extensive analysis of opponents' tactical behaviours
Representative learning tasks - practice task constraints encompass action opportunities similar to the competitive performance environment so that players can maintain the same perceptual-motor relations with critical competitive constraints	***Content didactical development*** – Three types of instructional types were implemented: (i) acquisition, based on the performance of a particular skill (e.g., setting action) (ii) structuring, focused on the comprehension of the tactical and technical skills within the game context without opposition (iii) adaptation, where the technical and tactical action structures were identical to the competition. The adaptation tasks included thematic games, where was emphasised the specific technical-tactical skills without ignoring the main game goal (e.g., giving extra points to positive defense actions), and small sided and conditioned games in which were emphasised specific tactical issues (e.g., block priorities).