Universidade de Lisboa
Faculdade de Motricidade Humana

Constraints-led Approach and Synergetic Behaviour in Volleyball Performance

Tese especialmente elaborada para a obtenção do grau de doutor em Motricidade Humana, na Especialidade de Treino Desportivo

Orientadores: Prof. Doutor Duarte Fernando da Rosa Belo Patronilho de Araújo
Prof. Doutor Jorge Manuel Castanheira Infante

Paulo Jorge Pereira Caldeira
2021

Universidade de Lisboa
Faculdade de Motricidade Humana

Constraints-led Approach and Synergetic Behaviour in Volleyball Performance

Tese especialmente elaborada para a obtenção do grau de doutor em Motricidade Humana, na Especialidade de Treino Desportivo

Júri

Presidente: Doutor Francisco José Bessone Ferreira Alves
Professor Catedrático e Presidente do Conselho Científico
Faculdade de Motricidade Humana da Universidade de Lisboa

Vogais: Doutor Duarte Fernando da Rosa Belo Patronilho de Araújo
Professor Associado com Agregação
Faculdade de Motricidade Humana da Universidade de Lisboa

Doutor Ludovic Seifert
Professeur Universités
Faculté des Sciences du Sport, Université de Rouen, Normandia, França

Doutora Paula Lanna Silva
Assistant Professor
Psychology Department, da University of Cincinnati (EUA)

Doutor Pedro José Madalena Passos
Professor Auxiliar com Agregação
Faculdade de Motricidade Humana da Universidade de Lisboa

Doutor António Paulo Pereira Ferreira
Professor Auxiliar
Faculdade de Motricidade Humana da Universidade de Lisboa

Orientadores: Prof. Doutor Duarte Fernando da Rosa Belo Patronilho de Araújo
Prof. Doutor Jorge Manuel Castanheira Infante

Paulo Jorge Pereira Caldeira
2021

Declaração de Reprodução da Tese

Nome: Paulo Jorge Pereira Caldeira

Endereço eletrónico: paulocaldei@gmail.com

Telefone: +351 919184637

Número do Cartão de Cidadão: 9585199

Título da tese : Constraints-led Approach and Synergetic Behaviour in Volleyball Performance

Orientadores: Prof. Doutor Duarte Fernando da Rosa Belo Patronilho de Araújo

Coorientador: Prof. Doutor Jorge Manuel Castanheira Infante

Ano de conclusão: 2021

Ramo de Conhecimento do Doutoramento: Motricidade Humana – Treino Desportivo

É AUTORIZADA A REPRODUÇÃO INTEGRAL DESTA DISSERTAÇÃO APENAS PARA EFEITOS DE INVESTIGAÇÃO, MEDIANTE DECLARAÇÃO ESCRITA DO INTERESSADO, QUE A TAL SE COMPROMETE.

Faculdade de Motricidade Humana – Universidade de Lisboa

Crus Quebrada, 23 de novembro de 2021

Assinatura:

Paulo Caldeira

(Paulo Jorge Pereira Caldeira)

Para o meu pai

Agradecimentos

Na conclusão desta tese sinto um dever de gratidão não só aos que diretamente a tornaram possível, mas também aos que pelo seu apoio, compreensão ou exemplo me transmitiram a força necessária.

Um agradecimento especial ao meu pai que sempre me apoiou e enalteceu o valor do conhecimento. Sei que se sentiu feliz por me ver iniciar este projeto, só lamento não ter presenciado a sua conclusão. Agradeço à minha mãe por todo o apoio, agora e sempre. Agradeço aos que mais abdicaram para que eu pudesse dedicar-me a esta tese, à minha mulher por todos os momentos de apoio e compreensão, à minha filha por todas as brincadeiras adiadas e ao meu filho por tão naturalmente acreditar no pai.

Agradeço ao meu amigo Frederico Raposo pelo incentivo, o conhecimento partilhado e sobretudo por estar sempre presente nos momentos mais difíceis. Ao Pedro Cardoso pelas conversas desafiadoras e enriquecedoras. Ao Rui Batalau pelo incentivo e exemplo. Agradeço à Paula Bettencourt, irmã de pais diferentes, a inspiração de uma vida.

Agradeço ao meu orientador, professor doutor. Duarte Araújo, que exemplarmente me guiou no trabalho, mas acima de tudo agradeço a forma humanista como sempre lidou comigo. Saí sempre das nossas reuniões com a motivação para enfrentar qualquer tarefa e com a fé em mim próprio renovada. Mais do que a concluir uma tese ajudou-me a entender uma nova perspetiva do conhecimento e que uma vez vista não pode deixar de o ser.

Agradeço ao meu co-orientador, professor doutor Jorge Infante, sem o qual não teria sido possível realizar os estudos planeados. Mas devo-lhe um agradecimento bem mais extenso e com origem muito anterior. Tudo o que me ensinou enquanto treinador e do que significa ser treinador, terá sido em muito responsável por “voleibol” fazer parte do título desta tese.

Agradeço à professora doutora Ana Paulo pela inestimável ajuda e conhecimento partilhado. Pela forma como partilhámos o trabalho desconfio que tínhamos feito uma boa dupla num qualquer campo de voleibol.

Agradeço aos professores doutores Orlando Fernandes, Sérgio T Fonseca e António Veloso toda a ajuda e ensinamentos que me proporcionaram.

Agradeço aos professores doutores Pedro Passos e António Paulo Ferreira a preciosa contribuição dada nos momentos das CATs.

Agradeço ao Sport Lisboa e Benfica na pessoa do professor José Jardim e do treinador Fernando Novo pela disponibilidade para a realização do estudo apresentado no

subcapítulo 3.3. Agradeço ao Clube de Futebol os "Belenenses" na pessoa do treinador João Correia e da treinadora Rita Fernandes pela disponibilidade para a realização dos estudos apresentados nos subcapítulos 3.1. e 3.2. Agradeço aos atletas que participaram nos estudos experimentais.

Agradeço aos colegas do SpertLab Inês Santos e Daniel Carrilho pela disponibilidade sempre imediata para ajudar.

Gostaria de também agradecer aos professores doutores Luís Sardinha e Pedro Mil-Homens que há mais de 20 anos atrás (na licenciatura) me inspiraram a querer saber mais e confirmaram que este era o meu caminho.

Acknowledgements

I would like to thank Professor Keith Davids for the opportunity and say that was for me a privilege to write together an article that is part of this thesis.

Papers that integrate the present thesis:

Sub-chapter 2.1

Caldeira, P., Paulo, A., Infante, J., & Araújo, D. (2019). A influência da pedagogia não-linear e da abordagem baseada nos constrangimentos no treino do remate no voleibol. *Retos. Nuevas Tendencias En Educación Fisica, Deporte y Recreación*, *36*(2), 484–490.

Sub-chapter 2.2

Caldeira, P., Davids,K. & Araújo, D. (accepted for publication) Neurobiological tensegrity: The basis for understanding inter-individual variations in task performance? *Human Movement Science*

Sub-chapter 2.3

Caldeira, P., Fonseca, S. T., Paulo, A., Infante, J., & Araújo, D. (2020). Linking Tensegrity to Sports Team Collective Behaviors: Towards the Group-Tensegrity Hypothesis. *Sports Medicine - Open*. https://doi.org/10.1186/s40798-020-00253-y

Sub-chapter 3.1

Caldeira, P., Infante, J. & Araújo, D. (under submission) Accommodating individual differences in a team: the practice of the volleyball spike

Sub-chapter 3.2

Caldeira, P., Paulo, A., Fernandes, O., Infante, J., & Araújo, D. (under submission) Perceptual attunement and meaningful ongoing adjustment group actions increase defensive ball contact effectiveness in volleyball.

Sub-chapter 3.3

Caldeira, P., Paulo, A., Veloso, A., Infante, J., & Araújo, D. (under submission) Functional variability facilitates goal-achievement in volleyball attack: an ecological dynamics approach.

Communications related to the present thesis:

Caldeira, P & Araújo, D. (2015). A influência do treino não-linear numa ação tática no voleibol. *XIX Jornadas da Sociedade Portuguesa de Psicologia do Desporto*, Guarda.

Caldeira, P., Paulo, A., Infante, J., & Araújo, D. (2017) Constraints-led Approach: Calibration in a Volleyball Action. Complex Systems in Sport - International Congress, Barcelona.

Caldeira, P & Araújo, D. (2019). Pedagogia Não-Linear: Evidência e Complementaridade. Simpósio Teoria da Autodeterminação e Pedagogia Não-Linear: Aplicações Práticas na Atividade Física. *XIX Jornadas da Sociedade Portuguesa de Psicologia do Desporto. XVI Congresso Andaluz y III Luso-Andaluz de Psicologia de La Actividad Fisica y el Deporte, Maia.*

Constraints-led Approach and Synergetic Behaviour in Volleyball Performance

Abstract

The aim of this thesis was to research the Constraints-led Approach (CLA) and synergetic behaviour in volleyball performance. Grounded on ecological dynamics framework we researched theoretically concepts related to individual and collective synergetic behaviour and experimentally implemented the CLA with volleyball teams. First, we presented a narrative review on the principles of CLA and nonlinear pedagogy providing two practical examples to apply to the sub-phase of volleyball attack. Next, we advanced a position statement and a novel hypothesis on the crucial role of biotensegrity structures in individual and collective coordinative structurers (i.e., synergies). In the experimental studies we implemented CLA to guide the performers trough the phases of *"Search", "Discover"* and *"Exploit"*. First, with a team of young female volleyball players we manipulate task constraints to accommodate individual differences and compare spike accuracy after training as well as understand time strategies in the coordinative structure of the horizontal approach. Results show that accommodating individual differences enhances performance (i.e., spike accuracy) and freezing degrees of freedom maintaining high variability in a component of the coordinative structure of the horizontal approach was the strategy of movement re-organization associated with higher spike accuracy. Next, we implemented a study with expert female volleyball players to compare frequencies of defensive ball contacts between real game, traditional defense strategy and "online" attunement to specifying variables. Additionally, we measure group synchronization in successful and unsuccessful defense situations. Results show that collectively attuning to relevant information promotes significant higher frequencies of defense ball contact than pre-determined strategies of action and successful defensive plays are associated with "online" significant changes in group synchronization. Finally, with young male elite volleyball players we aimed to compare the effects of training based on CLA principles to a traditional approach on attack performance. Also, aimed to predict what spatial temporal variables were exploited by the players to achieve successful attacks. Results showed a significant improvement in attack performance for CLA, and we found that variability at the end of the planting step and consistency at ball contact increased the chances of a successful attack.

Keywords: Ecological approach; individual differences; perceptual attunement; functional variability; synergies.

Abordagem Baseada nos Constrangimentos e Comportamento Sinergético na Performance em Voleibol

Resumo

O objetivo desta tese foi investigar a Abordagem Baseada nos Constrangimentos (ABC) e comportamento sinergético no voleibol. Enquadrados pela dinâmica ecológica investigámos conceitos teóricos relacionados com o comportamento sinergético individual e coletivo e aplicamos a ABC em equipas de voleibol. Inicialmente, apresentámos uma revisão narrativa dos princípios da ABC e pedagogia não-linear sugerindo dois exemplos para aplicação em treino. De seguida, produzimos dois artigos de opinião sobre o papel das estruturas de biotensegridade no comportamento sinergético individual e coletivo. Nos estudos experimentais implementámos a ABC para guiar os atletas através das fases de *"Search", "Discover"* e *"Exploit".* Primeiro, numa equipa de cadetes feminina manipulámos os constrangimentos da tarefa de forma a respeitar as diferenças individuais e comparar a precisão no remate após o treino, assim como, analisar a estratégia temporal na estrutura coordenativa da corrida e chamada de remate. Os resultados mostram que respeitar as diferenças individuais promovem melhor performance (i.e., na precisão do remate) e que congelar os graus de liberdade numa componente da estrutura coordenativa da chamada foi a estratégia associada com mais precisão no remate. De seguida, implementámos um estudo com jogadoras peritas para comparar frequências de contacto na defesa entre o jogo formal, a estratégia tradicional de defesa e a estratégia de coletivamente atender a variáveis especificadoras no decorrer da jogada. Adicionalmente, medimos a sincronização da defesa em situações de sucesso e insucesso defensivo. Resultados mostram que coletivamente atender a variáveis especificadoras no decorrer da jogada promove maior frequência de contactos e que as jogadas de sucesso defensivo estão associadas a alterações na sincronização no decorrer da jogada. Por último, com jogadores jovens de elite comparámos os efeitos na performance de ataque entre treinar de acordo com os princípios da ABC e com uma abordagem tradicional. Também tivemos como objetivo predizer quais as variáveis espácio-temporais que foram exploradas pelos jogadores nos ataques com sucesso. Resultados mostram um aumento da performance com a ABC e que variabilidade na chamada e consistência no ponto de contacto da bola aumenta a probabilidade de atacar com sucesso.

Palavras-chave: Abordagem ecológica; diferenças individuais; afinação perceptual; variabilidade funcional; sinergias.

Table of Contents

List of Figures

Figures were numbered following the chapter number

List of Tables

Tables were numbered following the chapter number

List of Abbreviations

CLA constraints-led approach

DAL deep anterior line

SBL superficial back line

SAL superficial anterior line

LL lateral line

SL spiral line

BFL back functional line

FFL front functional line

AL arm lines

COM center of mass

IGC individuality in group condition

GGC general group condition

OS Pre – Orientation Step Pre-test

OS Post - Orientation Step Post-test

OS FU - Orientation Step Follow up test

PS Pre – Planting Step Pre-test

PS Post - Planting Step Post-test

PS FU - Planting Step Follow up test

TO Pre – Take-off Pre-test

TO Post - Take-off Post-test

TO FU - Take-off Follow up test

DOF degrees of freedom

IQR interquartile range

TEM technical error measurement

CPA cluster phase analysis

1 General introduction

1.1 Introduction

The thesis presented here is a result of theoretical and experimental research with the underling objective of usefulness to sport practitioners, specifically those who teach and train volleyball teams. Accordingly, in experimental settings, research was focus on applicable concepts of skill acquisition and synergetic behavior in volleyball and compared with more traditional perspectives of training (Gentile, 1972; Schmidt, 1975). The Constraints-Led Approach (CLA) (Davids, Araújo, Shuttleworth, & Button, 2003) grounded on ecological dynamics theoretical foundations (Araújo, Davids, & Renshaw, 2020) and nonlinear pedagogy (Chow et al., 2016) was the applicable framework implemented in the experimental studies presented in this thesis. Ecological dynamics based on Gibson's theory of perception (Gibson, 1979) and dynamical systems theory (Kelso, 1995) situates the adaptive behavior of players at the level of the individual-environment system (Araújo, Davids, & Hristovski, 2006). Nonlinear pedagogy is learner-environment centered and informs CLA how to design training contexts that promotes self-organization under constraints with representative tasks based on relevant information-movement couplings (Button, Chow, & Rein, 2008; Renshaw, Chow, Davids, Hammond, & Hammond, 2010). When applying CLA is crucial to recognize the set of individual, task and environment constraints (Newell, 1986) that should be taken into account to promote a representative training design. The athlete's emergent behavior is constrained by his morphologic, genetic and psychologic characteristics; by properties of the environment such gravity, light, temperature and socio-cultural factors and by task specific objectives, rules, equipment used and organization (Araújo, 2006). In ecological dynamics, instructions and feedback are also considered task constraints that should be adequate to the individual (Chow et al., 2016). Constraints can be manipulated to enhance skill acquisition in sport, namely, by task design that guides the performer through the phases of: i) Search: exploring degrees of freedom to achieve a task goal; ii) Discover: exploring task solutions and stabilizing them; and iii) Exploit: exploiting perceptual-motor degrees of freedom (Renshaw et al., 2015). The phase *"Search"* relates to education of intentions as the performer searches the internal and external degrees of freedom that provide a way to achieve his goal. The phase *"Discover"* relates to education of attention where the performer discovers the appropriate perceptual attunement and learns which sources of information to attend. The phase *"Exploit*" relates to calibration were the performer exploits system degeneracy to situational demands and effective goal achievement (Davids, Araújo, Hristovski, Passos, & Chow, 2012). These

3 phases proposed by CLA that should be considered as concurrent and not as a sequence framed the research questions and hypotheses tested in our experimental work. What are the effects on performance of: i) implementing CLA accommodating individual differences, ii) collectively educating attention to specifying variables and iii) promoting constrained task variability? These were the main questions that guided our experimental studies and are related to the aforementioned phases of skill acquisition.

Also relevant to the purposes of the present thesis was the ecological dynamics perspective of synergetic behavior (Araújo, Silva, & Davids, 2015) and the work of Nicolai Bernstein on coordination of movements (Bernstein, 1996). Additionally, the concept of tensegrity structures (Turvey & Fonseca, 2014) was integrated into both ecological dynamics and Bernstein's theories, to advance novel hypotheses on the basis of inter-individual variation in task performance and team's collective behavior. Previous research established nonlinearity in learning and development (Davids, Button, & Bennett, 1999; Newell, Liu, & Mayer-Kress, 2001) and the importance of individual variation on understanding functionality (Davids, Bennett, & Newell, 2006). However, the basis of such variation is still not clear, and we took upon the task of advancing theoretical work on the inter-variation of coordinative structures (i.e., synergies) in the performer-environment system. From the ecological dynamic's perspective, functional group synergies rely on the perception of shared affordances and require specific analytical tools to capture collective behavior variables that describe teams' synergies (Araújo & Davids, 2016). Focusing on volleyball defense we advanced with a novel hypothesis of collective behavior grounded on tensegrity properties (Juan & Mirats Tur, 2008; Scarr, 2014) and in an experimental setting implemented and adapted to volleyball specific constraints a method (Cluster Phase Analysis) to measure group synchronization (López-Felip et al., 2018).

1.2 Outline of the present thesis

The present thesis is comprised of six articles: i) one narrative review article, ii) two current opinion articles and iii) three experimental studies. These articles are published, accepted for publication or under submission in peer-review journals with WoS impact factor and are presented here in the format requested by the correspondent journal. Five articles were written in English language and one in Portuguese. The structure of thesis is composed by four major chapters. The chapter two and three corresponds to the theoretical contribution and the experimental studies of our research to the topic of constraints-led approach and synergetic behavior in volleyball. These two chapters are divided in three sub-chapters, each corresponding to one article. A general introduction and general discussion (chapter four) are presented with the corresponding references at the end of the thesis (chapter five).

The general aim of the thesis was to implement the CLA in volleyball attending to the concurrent phases of search, discover, exploit and also research synergetic behavior from the ecological dynamics' perspective.

The first sub-chapter of our theoretical contribution to the topic of CLA and synergetic behavior in volleyball is a narrative review article (*The influence of nonlinear pedagogy and constraints-led approach on volleyball attack training*) on the principles of CLA and nonlinear pedagogy also providing two practical examples to apply to the sub-phase of volleyball attack. Since the article was written in Portuguese, we provide here a brief summary.

The CLA is informed by a nonlinear pedagogy (Chow et al., 2016) that provides the necessary pedagogical tools to learning and training sports movements (Chow et al., 2007). Nonlinear pedagogy is a learner-centred framework to training design that implies to (Chow, 2013; Correia et al., 2019):

i) Ensure an ecological practice context by providing functional affordances (i.e., opportunities for action) based on a representative process of perception-action
ii) To manipulate task constraints that guide the athlete to explore functional solutions
iii) To provide instructions with an external focus of attention, and
iv) To understand variability of movement as an essential part of the learning process.

In team sports, the game can be considered a complex dynamic system with multiple components interacting and evolving over time where perceptual attunement and tactical actions are close related (Araújo & Volossovitch, 2005; Serra-Olivares & García-Rubio, 2017). The game of volleyball is a highly dynamic and complex context with emergent information resulting from the interaction between the player and their team, the opponents, the constraints of the court and the ball. For example, the attack actions in volleyball requires to intercept the ball in the air, hitting the ball with power and direction while avoiding the net and the opponent's block. Research in volleyball framed by ecological dynamics showed that expert players adapt their actions to game changing constraints rather than using the theoretical ideal technic (Paulo et al., 2016) and that CLA is a suitable practical tool to enhance coordination and learning in volleyball (Davids, Bennett, Handford, & Jones, 1999). Framed by CLA and nonlinear pedagogy we present two training tasks (figure 2.1 and 2.2) for volleyball attack with block opposition. Both tasks are representative of the performance context expressing a common situation of the game, that is, attack with block opposition after defense of a free ball that allows the set to be performed from an ideal zone (Afonso, Esteves, Araújo, Thomas, & Mesquita, 2012; Afonso et al., 2010). Task manipulation is implemented by constraining the block actions to the attack in zone 4 (fig. 2.1) and zone 4 and 2 (fig.2.2). In Figure 2.1 the blockers are instructed to cover either the diagonal, the line or leave a space between blockers. In Figure 2.2 the number of blockers and coverage area are constrained creating a situation of one blocker covering diagonal, one blocker covering the line or two blockers covering either diagonal or the line. These block actions are common in the game (Araújo, Castro, Marcelino, & Mesquita, 2010) and would be performed by the blockers according to the coach instructions with the attackers not knowing which one would occur at each trial. Instructions with an external focus of attention (table 2.1) can be provided to the attackers before and during the task (e.g., "focus on the blockers movement" or "explore different angles of the horizontal approach") and questioning can be also be used during and after the exercise (e.g., "what relevant information is associated with successful trials?"). The ecological context of the tasks and the specific task manipulation will naturally lead to the movement variability proposed by nonlinear pedagogy. The set will be slightly different at each trial, the ball contact will occur in different locations of the three-dimensional space and it is expectable that spatial temporal variables of the horizontal approach will be different to overcome the block actions. We conclude that there is scientific evidence to advocate for the implementation of CLA to skill acquisition and development in sport teams such as volleyball and we provide two examples of task design that respect the principles of nonlinear pedagogy.

The second sub-chapter is a current opinion article (*Neurobiological tensegrity: The basis for understanding inter-individual variations in task performance?)* to the special issue of the Human Movement Science journal titled: *Can the Study of Individual Differences in Motor Learning Enhance our Understanding of the Development of Expertise.* Respecting individual differences in the learning and training process is major concern in the ecological dynamics' perspective (Davids et al., 2012) and inter-individual variation to learning/training stimulus is a well-established phenomenon (Liu, Mayer-

Kress, & Newell, 2006; Newell & Corcos, 1993). We make the position statement that individual's co-adaption to dynamic performance environment is supported by conceptualizing the musculoskeletal system as a tensegrity neurobiological system. We advance how the structure-function relationship in movement (re)organization in motor learning supports individual variations in skill development and performance by establishing how tensegrity properties are the basis of human movement, individualized perception-action and functional coordinative structures (i.e., synergies).

In the third sub-chapter is presented current opinion article (*Linking Tensegrity to Sports Teams Collective Behaviors: Towards the Group-tensegrity Hypothesis)* where we expand on tensegrity properties as the basis of sports team's synergetic behavior. Properties of group synergies (Araújo & Davids, 2016) are reviewed and the concept of tensegrity and biotensegrity (Scarr, 2014; Turvey & Fonseca, 2014) are clarified. Additionally, an example of volleyball defense sub-phase is used to link tensegrity properties to adaptive collective behavior.

"Search" is the first sub-chapter of our experimental studies where is presented the original research article (*Accommodating individual differences in a team: the practice of the volleyball spike)*. Constraint's manipulation in the CLA guides the performer through the phase of "search" where education of intentions promotes a convergency of task goals with the learner's goals (Jacobs & Michaels, 2007). Respecting individual differences is a fundamental aspect of the CLA and task manipulation should attend to the intrinsic dynamics of each performer (Renshaw et al., 2019). In this experimental study with young female volleyball players, court dimensions were accommodated based on an initial assessment of spike accuracy performance. We aimed to compare spike accuracy after training in court dimensions respecting individual differences and understand time strategies in the coordinative structure of the horizontal approach.

The second sub-chapter of our experimental studies relates to the phase of "Discover" and presents the original research article (*Perceptual attunement and meaningful ongoing adjustment group actions increase defensive ball contact effectiveness in volleyball*). In the phase "Discover" the performer identifies the appropriated use of sources of information while exploring task solutions (Davids et al., 2012). We implemented a cross-over design study with expert female volleyball players to compare frequencies of defensive ball contacts between real game, traditional defense strategy and "online" attunement to specifying variables. Additionally, we aimed to measure group synchronization in successful and unsuccessful defense situations.

The third sub-chapter of our experimental studies relates to the phase "Exploit" and presents the original research article (*Functional variability facilitates goal-achievement in volleyball attack: an ecological dynamics approach)*. In the "Exploiting" phase the performer scales their actions to the relevant information (calibration) which enables immediate adaptation to situational task demands (Davids, Button, Araujo, Renshaw, & Hristovski, 2006). We implemented an intervention experimental study with young male elite volleyball players aimed to compare the effects of training based on CLA principles to a traditional approach on attack performance. Also, aimed to predict what spatial temporal variables were exploited by the players to achieve successful attacks.

In chapter four we discussed how our theoretical work and results of the experimental studies contribute to the topic of CLA and synergetic behavior in volleyball. Suggestions of future research and practical implications are also addressed in chapter four.

.

2 Constraints-led approach and synergetic behavior in volleyball: A theoretical contribution

2.1 A influência da pedagogia não-linear e da abordagem baseada nos constrangimentos no treino do remate no voleibol[1]

The influence of nonlinear pedagogy and constraints-led approach on volleyball attack training

Caldeira, P., Paulo, A., Infante, J., & Araújo, D. (2019). A influência da pedagogia não-linear e da abordagem baseada nos constrangimentos no treino do remate no voleibol. *Retos. Nuevas Tendencias En Educación Fisica, Deporte y Recreación*, *36*(2), 484–490.

---

[1] The article is presented in this section in the language (Portuguese) it was written and published. A brief summary in English is provided in the general introduction.

2.1.1 Resumo

O objetivo deste artigo é rever os fundamentos teóricos da abordagem baseada nos constrangimentos e da pedagogia não-linear e como, de acordo com os seus princípios, poderá ser abordado o treino do voleibol. Neste sentido, para estruturar o treino de voleibol e melhorar o desempenho em jogo são desenvolvidos os princípios de manutenção do contexto ecológico, de manipulação da tarefa, de concentrar as instruções num foco externo valorizando os efeitos da ação e capitalizar a variabilidade do movimento. No voleibol o ataque é responsável pela maioria dos pontos efetuados, o que sublinha a importância do treino desta ação tática num contexto ecológico. São apresentados dois exemplos da aplicação da abordagem baseada nos constrangimentos e da pedagogia não-linear à subfase de ataque com oposição do bloco.

Palavras chave: Dinâmica ecológica; Pedagogia não-linear; Abordagem baseada nos constrangimentos; Voleibol

Abstract.

The objective of this article is to overview the principles of the constraints-led approach and nonlinear pedagogy and how they can be applied to volleyball training. To better structure volleyball training and enhance game performance are developed the principles of representative context, task manipulation, instructions based on external focus of attention highlighting the effects of the action and taking advantage on movement variability. In volleyball games, attack is responsible for the majority of points, which highlights the importance of training this tactical action in a representative context. We present two examples of how to apply the constraints-led approach and nonlinear pedagogy to the sub-phase of attack with block opposition.

Keywords: Ecologic Dynamics; Nonlinear Pedagogy; Constraints-led Approach;
Volleyball

2.1.2 Introdução

Os princípios associados a uma visão tradicional do treino sustentam-se numa lógica linear de causa efeito assumindo que as mesmas causas geram os mesmos efeitos. Esta visão resulta de uma abordagem do treino desportivo do analítico para o global e do simples para o complexo. São exemplos, a repetição frequente de um movimento considerado ideal ou treino de variações limitadas desse mesmo movimento (Schmidt, 1975). Todavia, a dinâmica ecológica desafia alguns destes conceitos tradicionais relativamente à aprendizagem motora. Aqui o movimento desportivo resulta da interação entre o praticante e o contexto, com propriedades emergentes e de auto-organização (Araújo, Davids, & Hristovski, 2006). A dinâmica ecológica serve de base à Abordagem Baseada nos Constrangimentos (Davids, Araújo, Shuttleworth, & Button, 2003), por sua vez, uma plataforma adequada a um enquadramento pedagógico não-linear nos processos de aquisição motora e do treino.

Encontramos na pedagogia não-linear (Chow et al., 2007) pressupostos que respeitam esta abordagem ecológica relativamente à aquisição e treino dos movimentos desportivos, assim como, à aprendizagem e treino dos jogos coletivos e das ações táticas que lhes são inerentes (Tan, Chow, & Davids, 2012). Nos jogos coletivos, como o voleibol, a tomada de decisões mais apropriadas também pode ser potenciada por uma abordagem ao treino que incentive a resolução dos problemas emergentes associados ao jogo (Mesquita, 2005). Pretendemos, assim, rever os pressupostos da abordagem dinâmica ecológica na aprendizagem motora, a qual serve de base teórica da pedagogia não-linear, no sentido de informar como o treino das ações nos jogos coletivos, em particular no voleibol, podem ser realizadas sob este enquadramento.

2.1.3 Fundamentos da Pedagogia Não-Linear

Bernstein (1967) formulou o problema dos graus de liberdade, em que as inúmeras possibilidades de movimento que o sistema motor oferece constituem um problema, mas também oferecem ao praticante um vasto conjunto de soluções para a resolução de uma dada tarefa. Bernstein foi precursor ao apresentar formalismos que demonstram como a coordenação motora está associada ao domínio dos graus de liberdade possíveis para um dado movimento (Bernstein, 1967). Deste ponto de vista, o processo de aprendizagem não é linear, ao invés, envolve alterações descontínuas no comportamento ao longo do tempo (Kelso, 1995).

No desporto encontramos uma extensa riqueza de expressão motora em variados contextos de performance. O comportamento motor expresso nos diferentes desportos emerge da natureza dos constrangimentos que lhe são próprios e que dessa forma são impostos ao praticante (Araújo, 2006).

Fundamentada no trabalho de Newell (1986) a Abordagem Baseada nos Constrangimentos (ABC) implica reconhecer três categorias de constrangimentos: do praticante, do ambiente e da tarefa (Newell, 1986). O comportamento emergente é constrangido por características morfológicas, genéticas e psicológicas do praticante; por características do ambiente como a gravidade, luz, temperatura e fatores socio-culturais; e pela tarefa, os seus objetivos, regras especificas do desporto, características dos exercícios e equipamento utilizado (Araújo, 2006). Na dinâmica ecológica a informação verbal em forma de instruções, questões ou feedback é um constrangimento mais associado à tarefa, embora tão adequado quanto possível ao individuo (Chow, Davids, Button, & Renshaw, 2016). É importante notar que as três categorias de constrangimentos não atuam de forma independente. Ao invés, o comportamento motor emerge da interação dinâmica entre praticante, ambiente e tarefa na procura de soluções estáveis e funcionais dentro das possibilidades existentes (Tan et al., 2012). No desporto, os atletas procuram a estabilidade e flexibilidade de sinergias musculares funcionais ficando mais afinados perceptivamente aos constrangimentos relevantes num dado contexto de performance (Davids, Bennett, Handford, & Jones, 1999). Portanto, os constrangimentos canalizam a emergência do comportamento motor e decisional, na procura de um estado estável de organização (Newell, 1986).

Baseada nestes pressupostos, a Pedagogia Não-Linear (PNL) tem vindo progressivamente a afirmar-se como uma opção pertinente relativamente à estrutura da prática, à melhoria do desempenho e de como transmitir instruções particularmente relevantes à aprendizagem (Chow, Renshaw, Button, Davids, & Tan, 2013). A PNL permite aos professores e treinadores aplicar os conceitos sustentados pela psicologia ecológica e pela teoria dos sistemas dinâmicos, i.e., desenvolver uma prática guiada pela abordagem teórica da dinâmica ecológica (Chow et al., 2006). A PNL tem como pressupostos (Chow, Davids, Button, & Renshaw, 2016; Chow, 2013):

i) garantir um contexto ecológico da prática providenciando ao praticante "affordances" (oportunidades para a ação) funcionais que reflitam um processo de percepção-ação relevante;

ii) manipular os constrangimentos da tarefa de forma a permitir ao praticante explorar as soluções mais adequadas para si;

iii) concentrar as instruções num foco externo valorizando os efeitos da ação e

iv) entender a variabilidade do movimento como fator essencial do processo de aprendizagem motora.

Por exemplo, Hristovski, Davids e Araújo (2006) demonstraram estes pressupostos ao estudar pugilistas que tinham como tarefa desenvolver sequências de punhos para um saco de boxe. A manipulação da distância do pugilista ao saco, tendo em conta o comprimento dos braços, fez emergir diferentes possibilidades de ação a diferentes distâncias do alvo. A variabilidade das ações foi produzida por um efeito dinâmico não-linear que por sua vez foi gerado pela alteração da percepção da informação, decorrente da distância relativa ao saco (Hristovski, Davids, & Araújo, 2006). A manipulação dos constrangimentos e da variabilidade da tarefa conduz o praticante, não só a soluções funcionais de movimento, como a novas soluções para a resolução do problema (Chow, Davids, Hristovski, Araújo, & Passos, 2011). Noutro exemplo, Schöllhorn e colegas (2010) provocaram perturbações estocásticas (aleatórias) durante as tarefas de aprendizagem dos movimentos da corrida de barreiras incentivando a descoberta de soluções que mais se adequavam ao praticante. Comparativamente a uma abordagem baseada na repetição, verificou-se maior instabilidade durante os treinos, mas resultou num grau superior de estabilidade do movimento aprendido (Schöllhorn, Beckmann, Janssen, & Drepper, 2010).

Relativamente à variabilidade do movimento, as teorias clássicas da aprendizagem têm relacionado o controlo e coordenação motora com um mecanismo imposto pelo Sistema Nervoso Central onde se pressupõe um processo linear entre o “input” e o “output”. O ruído, inerente aos sistemas biológicos, expresso na variabilidade do movimento é visto como algo a eliminar através da prática e da repetição (Button, Lee, Mazumder, Tan, & Chow, 2012). Embora se reconheça que nem todo o ruído é benéfico no processo de aprendizagem, a manipulação cuidada dos constrangimentos, em especial da tarefa, pode limitar os graus de liberdade àqueles relevantes para o praticante (Chow et al., 2011). Por exemplo, num estudo de Schöllhorn, Beckmann, Michelbrink, Sechelmann, Trockel, & Davids, (2006) um grupo de praticantes de futebol expostos a constantes variações de movimento na execução de dribles e passes, evitando a repetição e encorajados a uma prática exploratória, obteve resultados superiores comparativamente ao grupo que abordou o treino de drible e passe de forma mais tradicional focado na técnica considerada ideal (Schöllhorn, Michelbrink, Beckmann, Trockel, Sechelmann, &

Davids, 2006). Também, Araújo, Davids, Bennett, Button, e Chapman, (2004) verificaram que, no 1x1 no basquetebol, os jogadores atacantes que apresentavam maior variabilidade de movimento perto do defensor tinham mais sucesso em ultrapassá-lo e progredir para o cesto, comparativamente aos jogadores que apresentavam menor variabilidade de movimento (Araújo, Davids, Bennett, Button, & Chapman, 2004). A variabilidade é inerente e inevitável no sistema de movimento humano (Davids, Bennett, & Newell, 2006) deixando a professores e treinadores o foco em "como", "em que quantidade", "para quem" e "para quê" (Cardis, Casadio, & Ranganathan, 2017).

Em conclusão, a PNL fornece um enquadramento para a construção de programas de aprendizagem e treino que garantem um contexto ecológico da prática, conduzindo o processo pela manipulação cuidada dos constrangimentos relevantes e abraçando a variabilidade como fator positivo (Chow et al., 2006).

2.1.4 Pedagogia Não-Linear nos Jogos Coletivos

O comportamento motor tem sido sobretudo estudado numa perspetiva individual, mas a dimensão coletiva, tem sido alvo de interesse crescente. Por exemplo, Passos e colegas estudaram o comportamento da díade atacante-defesa no rugby verificando que as decisões e ações dos intervenientes são emergentes, com propriedades de auto-organização (Passos et al., 2009). De acordo com Button e colegas (2012) este estudo proporcionou uma forte evidência da relação entre a teoria dos sistemas dinâmicos e as subfases de modalidades coletivas como o rugby (Button et al., 2012).

Nos desportos coletivos, o jogo pode ser visto como um sistema complexo dinâmico, isto é, composto de múltiplos componentes que interagem e evoluem no tempo e onde a afinação perceptiva e a ação tática são inseparáveis (Araújo & Volossovitch, 2005; Serra-Olivares & García-Rubio, 2017) Nestes desportos, o conhecimento e as decisões táticas a aprender podem ser apresentados através de tarefas (Cantos, Moreno, Miguel, & España, 2019). Nestas tarefas, a manipulação dos constrangimentos (e.g. SSCG-Small-Sided and Conditioned Games) é feita de modo a permitir aos jogadores explorarem soluções funcionais com vista à concretização de um dado objectivo tático. SSCG permitem aos praticantes um elevado volume de oportunidades de afinação perceptiva a informação relevante, assim como, moldar a emergência de ações e tomada de decisão (Davids, Araújo, Correia, & Vilar, 2013). Por exemplo, no contexto do futebol Fenoglio (2003) demonstrou que jogos de 4 v 4 em vez de 8 v 8 aumentam a frequência das ações (mais 135% de passes; mais 260% mais remates; mais 500% golos), proporcionando aos praticantes uma oportunidade para melhor desenvolverem as suas competências (Fenoglio, 2003).

O jogo de voleibol promove um ambiente complexo e dinâmico com informação emergente resultante da interação entre o praticante e os colegas de equipa, os adversários, o espaço físico e a bola, que não pode ser agarrada. A ação de ataque em voleibol, por exemplo envolve, não só interceptar no ar a bola, como também conferir-lhe potência e direção, atendendo aos obstáculos da rede e do bloco. É um exemplo que reflete a elevada complexidade do contexto com que o atleta interage. Neste contexto dinâmico as oportunidades para agir surgem e desaparecem continuamente não só na ação de remate, mas em outras ações do jogo.

Davids et.al (1999) sustentam a utilização da abordagem baseada nos constrangimentos para facilitar a coordenação na aprendizagem do serviço de voleibol. Estudando atletas experientes, os autores verificaram que a invariante de sucesso é o pico de altura do lançamento da bola contribuindo assim com informação pertinente para o desenho representativo das tarefas de treino do serviço (Davids et al., 1999). Noutros estudos enquadrados na dinâmica ecológica, relativos a outra sub-fase do jogo (a receção) verificou-se que jogadores peritos exibem flexibilidade nas suas ações como forma de adaptação à variabilidade dos constrangimentos situacionais, de acordo com as affordances da situação, em vez de uma escolha pré-determinada de uma técnica específica (Paulo, Zaal, Fonseca, & Araújo, 2016; Paulo, Zaal, Seifert, Fonseca, & Araújo, 2018) Deste modo foi reforçada a premissa de que a seleção do modo de ação ocorre à escala indivíduo-envolvimento, não podendo portanto ser circunscrita ao indivíduo (Barsingerhorn, Zaal, De Poel, & Pepping, 2015).

No voleibol existem inúmeras circunstâncias que exigem a ação de saltar: bloco, remate, serviço em suspensão, passe em suspensão. Os jogadores percepcionam as oportunidades para agir de forma muito precisa como ficou evidenciado nos estudos de Pepping e Li (2000) quando é alterada a dinâmica do sistema actor-envolvimento através da manipulação da massa corporal ou da superfície de salto, a percepção dos limites do espaço de preensão altera-se em conformidade (Pepping & Li2, 2000).

Os atletas exploram continuamente o ambiente na busca das oportunidades de ação mais funcionais e fazem-no de forma muito precisa quando o contexto se altera. Neste sentido, o desenho da prática e das tarefas requer uma simulação do contexto competitivo que permita aos atletas "trabalharem" em subfases ou subcomponentes especificas do jogo (Davids, 2012), tal como o ataque através de remate, com oposição do bloco. Existe uma importância acrescida desta subfase devido à sua elevada frequência no jogo de voleibol (Araújo, Castro, Marcelino, & Mesquita, 2010; Castro, Souza, & Mesquita, 2011).

2.1.5 Abordagem Baseada nos Constrangimentos e Pedagogia Não-Linear no treino de uma ação tática de ataque no voleibol

No voleibol, independentemente do sexo, mais de metade dos pontos são conquistados através do ataque (Palao, Manzanares, & Valadés, 2015). No voleibol feminino de alto nível, o ataque é a ação de jogo mais relacionada com a vitória (Inkinen, Häyrinen, & Linnamo, 2013), sendo que o ataque ponto é uma das variáveis que discrimina entre ganhar e perder o set, em jovens do sexo masculino (García-Hermoso, Dávila-Romero, Saavedra & Garcia-Hermoso, 2013) e neste sentido a tomada de decisão no momento de finalizar a jogada é determinante para alcançar a vitória (Conejero, Claver, Fernández-Echeverría, Gil-arias, & Moreno, 2017). Já dentro das ações técnicas utilizadas no ataque, o remate é a técnica mais frequente no voleibol de alto nível – 87.9% no masculino e 77.7% no feminino, sendo que 52.1% no masculino e 44% no feminino destas ações resultam na obtenção de ponto (Palao, Manzanares, & Ortega, 2009). O sucesso do remate está relacionado com a potência e com a direção escolhida (Palao, Santos, & Urena, 2007) mas a sua eficácia diminui significativamente quando a bola toca no bloco (Rocha & Baranti, 2004). O bloco é o segundo fundamento técnico melhor correlacionado com a vitória e que pode neutralizar a ação de ataque (Junior, 2013). Estes dados sublinham a importância do treino tático de ataque com oposição. Na perspectiva da PNL o conhecimento do movimento ou a decisão da ação tática a realizar não é determinado por um controlador interno associado a níveis superiores do sistema nervoso, mas é antes resultante da interação do praticante com o contexto que através da prática melhora o acoplamento à informação contextual relevante para as ações a realizar (Tan et al., 2012). Planear no treino da ação tática de ataque com oposição do bloco sobre o ponto de vista da abordagem não-linear implica conceber que uma pequena alteração nos constrangimentos da tarefa (e.g. manipular as ações do bloco) pode provocar uma mudança significativa na aprendizagem. A variabilidade controlada (das ações do bloco) pode ter um papel funcional na exploração das soluções motoras (no ataque) para a resolução da tarefa e a variabilidade individual do movimento (gesto desviante do "ideal") contribui positivamente para a aprendizagem (Chow et al., 2011). Através de um cuidado desenho da tarefa é possível criar um ambiente exploratório aumentado, que promova maior flexibilidade na descoberta de soluções funcionais (mesmo que atípicas) para a resolução do problema.

Para o treino da ação tática de ataque com oposição do bloco propomos duas tarefas (Fig. 2.1 e Fig. 2.2) sustentada nos pressupostos da PNL (Chow et al., 2016; Chow, 2013).

2.1.5.1 Garantir um contexto ecológico da tarefa

A tarefa de treino reflete um cenário comum do jogo, isto é, a construção do ataque após defesa com 2 (Fig.2.2) ou 3 (Fig.2.1) possíveis zonas de remate (zona 2, 3 e 4) e oposição de 2 blocadores aos ataques realizados na zona 2 e 4. Desta forma as tarefas garantem que informação contextual relevante e similar ao jogo se encontra presente.

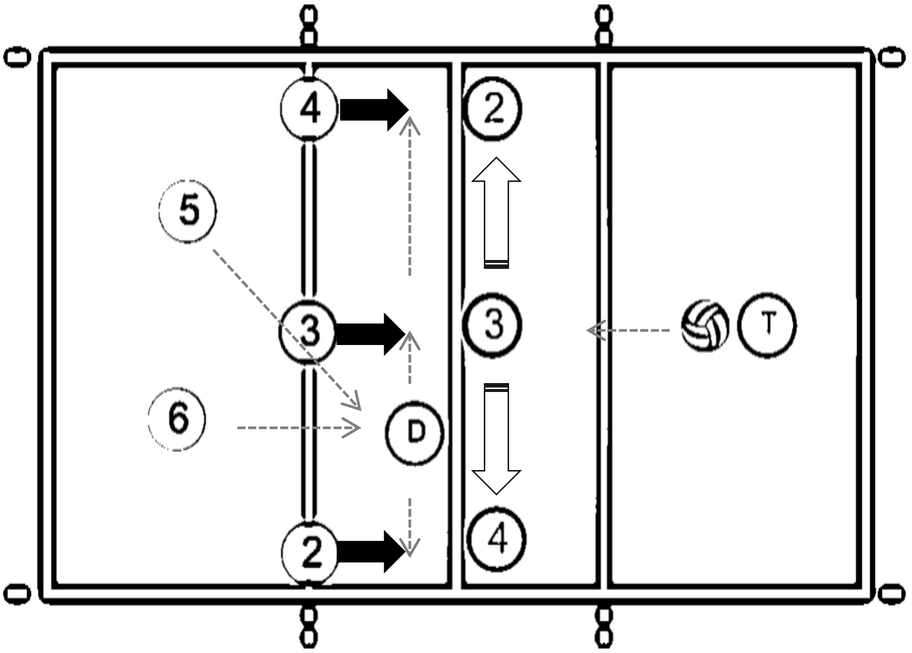


Figure 2. 1 Seta a cheio - zonas de ataque; seta fundo branco deslocamento dos blocadores; seta a tracejado deslocamento da bola; T treinador; D distribuído

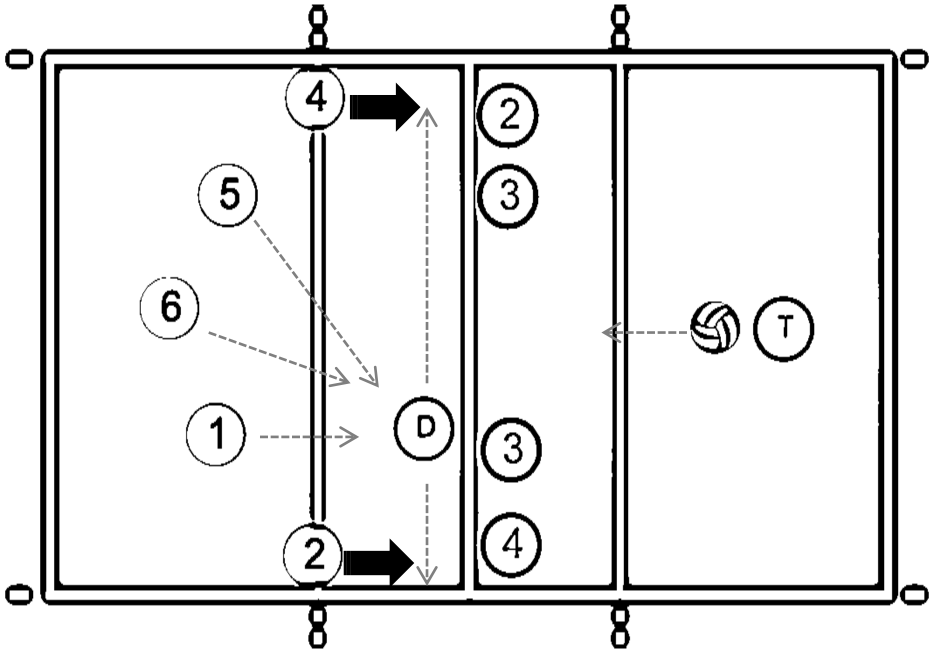


Figure 2. 2 Seta a cheio - zonas de ataque; seta a tracejado - deslocamento da bola; T treinador; D distribuidor.

Ambas as tarefas iniciam-se com bola "morta" (*free ball*) colocada pelo treinador promovendo assim um elemento facilitador do 1º toque e consequentemente que o passe para o ataque seja realizado da *"zona ideal"* (Afonso et al., 2010; Afonso, Esteves, Araújo, Thomas, & Mesquita, 2012). Com o passe realizado desta zona, teoricamente todas as opções de ataque são possíveis (Marcelino, 2008).

2.1.5.2 Manipular os constrangimentos da tarefa

Na visão da PNL manipular variáveis específicas da tarefa é uma forma de guiar o sistema de aprendizagem à exploração de novos estados funcionais de organização (Chow et al., 2011). Nas tarefas propostas a manipulação recai sobre a ação do bloco ao ataque de zona 4 no caso da tarefa apresentada na Fig. 2.1 e ao ataque de zona 4 e 2 no caso da Fig. 2.2. As ações do bloco deverão ser manipuladas da seguinte forma:

Fig. 2.1) Manipulação da área coberta pelo bloco. Os blocadores deverão receber instruções relativas a 3 ações de bloco específicas: bloco bem formado "fechando" o remate à paralela, isto é, impedindo o remate para a zona 2 e 1, bloco bem formado "fechando" o remate cruzado, isto é, impedindo o remate para a zona 5 e 4 e bloco com espaço entre os blocadores.

Fig. 2.2) Manipulação do número de blocadores e área coberta pelo bloco. Os blocadores deverão receber instruções relativas a 3 ações de bloco específicas: bloco com um jogador (exterior), bloco com um jogador (interior) ou bloco duplo.
Estas ações de bloco são comuns em jogo (Araújo, Castro, Marcelino, & Mesquita, 2010) e nestas tarefas os blocadores deverão executar as três ações numa ordem previamente definida no design experimental e comunicada pelo treinador. Os atacantes não terão conhecimento da ordem de ações do bloco.

2.1.5.3 Concentrar as instruções num foco externo valorizando os efeitos da ação

As instruções fornecidas ao praticante podem ser vistas como constrangimentos que ajudam a guiar as intenções, percepções e ações emergentes dos praticantes (Newell & Ranganathan, 2010). Na PNL o objetivo das instruções e do feedback é fornecer informação pertinente que facilite a procura de soluções de coordenação e controlo da tarefa (Chow et al., 2016). O foco de atenção deve ser externo, isto é, dirigido para os efeitos da ação (Hossener & Wenderoth, 2007; Wulf, Lauterbach, & Toole, 1999) ajudando os praticantes na exploração de soluções e contribuindo para a melhoria da performance na tarefa. Em movimentos complexos, como os apresentados nas tarefas propostas (fig.1 e fig.2), pode revelar-se difícil direcionar a atenção para a informação pertinente. Em cada repetição realizada o treinador pode constranger a atenção dos jogadores, para após realizarem a ação, focarem nas suas consequências. No entanto, em praticantes que realizem com sucesso as tarefas propostas (i.e., atletas de nível intermédio), neste caso o treinador pode direcionar a atenção dos jogadores para os efeitos de uma sub-fase da ação ou através do questionamento (Newell & Ranganathan, 2010). O questionamento em situação de grupo ou individual pode ser utilizado pelo treinador para guiar o processo exploratório dos atletas (explorara perceptualmente para detectar a informação para agir). Encorajar respostas através de analogias facilita a focalização na dinâmica da ação (Chow et al., 2016; Lam, Maxwell, & Masters, 2009) Nas tarefas acima propostas o treinador poderá utilizar instruções ou questionamento (tabela.1) em situação individual ou de grupo: por exemplo i) solicitar aos jogadores que foquem a sua atenção na movimentação dos blocadores; ou ii) solicitar que explorem uma posição inicial que permita vários ângulos de aproximação à rede; ou iii) questionar sobre a perceção do enquadramento com a bola em situação de sucesso versus insucesso. Estas práticas de instrução e questionamento podem ocorrer antes, durante ou depois da realização da tarefa conforme o seu conteúdo.

Tabela 2. 1 Exemplos de instrução e questionamento para as tarefas propostas

	Como	Quando
Instrução	• Incentivar que os jogadores observem as ações do bloco.	Antes e durante
	• Incentivar que os jogadores explorem as soluções que o bloco oferece.	Antes e durante
	• Incentivar que os jogadores explorem uma posição inicial da chamada que permita todos os ângulos de aproximação à rede.	Antes e durante
	• Incentivar que os jogadores explorem um enquadramento com a bola no momento do contacto que permita observar a bola e o bloco.	Antes e durante
Questionamento	• Questionar o jogador sobre o que percepcionou em relação ao seu enquadramento com a bola nas situações de sucesso e nas de insucesso.	Durante e após
	• Questionar o jogador sobre o que observa no bloco nas situações de sucesso e nas de insucesso.	Durante e após
	• Questionar o grupo sobre onde devem focar para atingir o sucesso na tarefa	Antes, durante e após
	• Questionar o grupo sobre qual a informação que guiava a ação bem sucedida de um determinado jogador.	Durante e após

2.5.4 Variabilidade do movimento

A variabilidade do movimento enquanto processo benéfico no processo de aprendizagem motora não deve ser confundido com variabilidade nos efeitos da ação (Komar, Chow, Chollet, & Seifert, 2015; Seifert et al., 2014; Wu, Miyamoto, Gonzales

Castro, Ölveczky, & Smith, 2014). A variabilidade de movimento tem o potencial de aumentar a flexibilidade das ações do praticante na procura de soluções e mesmo em atletas de elite verifica-se que não existe um padrão único de movimento para o mesmo objetivo (Schöllhorn & Bauer, 1998). No caso da tarefa proposta a variabilidade de movimento é inerente ao facto desta representar o contexto ecológico do jogo. O passe para o ataque nunca será exatamente igual e é previsível que em cada execução o atacante contactará a bola em pontos diferentes do espaço tridimensional e que as variáveis espaço-temporais da sua chamada de remate sejam diferentes.

2.1.6 Conclusão

O avanço no conhecimento dos sistemas complexos tem reforçado uma visão mais complexa, não-linear e ecológica da aprendizagem motora (Chow, 2013). Na abordagem baseada nos constrangimentos o praticante enquanto sistema dinâmico procura um estado estável e funcional de coordenação para a resolução das tarefas propostas (Button et al., 2012). Neste sentido, a PNL fornece o enquadramento para que os princípios pedagógicos possam ser aplicados levando em conta a não-linearidade de comportamentos associada à aprendizagem motora. Esta abordagem providencia aos professores e treinadores instrumentos para o desenho de tarefas representativas e para a manipulação dos constrangimentos, mantendo um foco de atenção no processo e valorizando a variabilidade funcional (Lee et al., 2014).

No voleibol, o contexto competitivo é dinâmico e em constante mudança criando a necessidade dos praticantes modelarem continuamente as suas ações à informação emergente. Esta necessidade implica funcionalidade, flexibilidade e constante regulação da percepção-ação na resolução das tarefas (Davids, 2012).

No voleibol, o ataque discrimina a vitória da derrota, já que resulta normalmente na obtenção de ponto. O remate é a técnica mais utilizada, mas o seu sucesso diminui significativamente quando a bola toca no bloco adversário, sendo crítica a inclusão da oposição do bloco no treino desta ação tática. Uma abordagem não-linear a esta subfase do jogo implica a manipulação cuidada da tarefa no sentido de uma representação ecológica da mesma abraçando a variabilidade individual como fator positivo na melhoria do desempenho dos praticantes. Implica aceitar que a manipulação dos constrangimentos associados à tarefa pode concorrer para maior variabilidade funcional nas ações do praticante e servir de catalisador para que surjam novos padrões movimento (Chow et al., 2011).

Consideramos assim existir suficiente evidência na literatura a suportar uma abordagem não-linear ao ensino de desportos como o Voleibol, em tarefas representativas do contexto competitivo, como a que aqui sugerimos – o ataque com oposição do bloco. Com base na ABC e PNL propomos uma tarefa de treino tático do ataque de zona 4 que pretende cumprir os pressupostos de representatividade, manipulação dos constrangimentos e variabilidade do movimento mantendo um foco externo de atenção.

2.1.7 Referências

Afonso, J., Esteves, F., Araújo, R., Thomas, L., & Mesquita, I. (2012). Tactical determinants of setting zone in elite men's volleyball. *Journal of Sports Science and Medicine*, *11*(1), 64–70.

Afonso, J., Mesquita, I., Marcelino, R., António, J., Alfonso, J., & Antonio, J. (2010). Analysis of the setter ' s tactical action in high-performance women ' s volleyball. *Kinesiology*, *42*(1), 82–89.

Araújo, D. (2006). *Tomada de Decisão no Desporto*. Faculdade de Motricidade Humana.

Araújo, D., Davids, K., Bennett, S., Button, C., & G, C. (2004). Emergence of sport skills under constraint. In A. M. Williams & N. J. Hodges (Eds.), *Skill acquisition in sport: Research, theory and practice* (pp. 409–433). London: Routledge.

Araújo, D., Davids, K., & Hristovski, R. (2006). The ecological dynamics of decision making in sport. *Psychology of Sport and Exercise*, *7*(6), 653–676. https://doi.org/10.1016/j.psychsport.2006.07.002

Araújo, D., & Volossovitch, A. (2005). Fundamentos para o treino da tomada de decisão: uma aplicação ao andebol. In D. Araújo (Ed.), *A acção táctica no desporto* (pp. 75–97). Visão e Contextos Lda.

Araújo, R. M., Castro, J., Marcelino, R., & Mesquita, I. R. (2010). Relationship between the Opponent Block and the Hitter in Elite Male Volleyball. *Journal of Quantitative Analysis in Sports*, *6*(4), 306–313. https://doi.org/10.2202/1559-0410.1216

Barsingerhorn, A. D., Zaal, F. T. J. M., De Poel, H. J., & Pepping, G. J. (2015). Shaping decisions in volleyball an ecological approach to decision-making in volleyball passing. *International Journal of Sport Psychology*, *44*(3), 197–214. https://doi.org/10.7352/IJSP.2013.44.197

Bernstein, N. A. (1967). The co-ordination and regulation of movements: Conclusions towards the Study of Motor Co-ordination. *Biodynamics of Locomotion*. https://doi.org/10.1097/00005072-196804000-00011

Button, C., Lee, C. M., Mazumder, A. D., Tan, W. K. C., & Chow, J. (2012). Empirical Investigations of Nonlinear Motor Learning. *The Open Sports Sciences Journal*, *5*, 49–58. https://doi.org/10.2174/1875399X01205010049

Cantos, J., Moreno, F. J., Miguel, U., & España, H. (2019). Pedagogía no lineal como método de enseñanza de los comportamientos tácticos en los deportes de equipo , aplicación al rugby Non-linear pedagogy as a method of teaching tactical behaviors in team sports , rugby application, *2041*, 402–406.

Cardis, M., Casadio, M., & Ranganathan, R. (2017). High variability impairs motor learning regardless of whether it affects task performance. *Journal of Neurophysiology*, jn.00158.2017. https://doi.org/10.1152/jn.00158.2017

Castro, J., Souza, A., & Mesquita, I. (2011). Attack efficacy in volleyball: elite male teams. *Perceptual and Motor Skills*, *113*(2), 395–408. https://doi.org/10.2466/05.25.PMS.113.5.395-408

Chow, J. Y. (2013). Nonlinear Learning Underpinning Pedagogy: Evidence, Challenges, and Implications. *Quest*, *65*(4), 469–484. https://doi.org/10.1080/00336297.2013.807746

Chow, J. Y., Davids, K., Button, C., & Renshaw, I. (2016). *Nonlinear Pedagogy in Skill Acquisition An Introduction*. (Routledge, Ed.).

Chow, J. Y., Davids, K., Button, C., Shuttleworth, R., Renshaw, I., & Araujo, D. (2007). The Role of Nonlinear Pedagogy in Physical Education. *Review of Educational Research*, *77*(3), 251–278 ST–The Role of Nonlinear Pedagogy in Ph. https://doi.org/10.3102/003465430305615

Chow, J. Y., Davids, K., Button, C., Shuttleworth, R., Renshaw, I., & Araújo, D. (2006). Nonlinear pedagogy: a constraints-led framework for understanding emergence of game play and movement skills. *Nonlinear Dynamics, Psychology, and Life Sciences*, *10*, 71–103.

Chow, J. Y., Davids, K., Hristovski, R., Araújo, D., & Passos, P. (2011). Nonlinear pedagogy: Learning design for self-organizing neurobiological systems. *New Ideas in Psychology*, *29*(2), 189–200. https://doi.org/10.1016/j.newideapsych.2010.10.001

Chow, J. Y., Renshaw, I., Button, C., Davids, K., & Tan, C. W. K. (2013). Effective Learning Design for the Individual: A Nonlinear Pedagogical Approach in

Physical Education. *Nonlinear Learning and Pedagogy.*

Conejero, M., Claver, F., Fernández-Echeverría, C., Gil-arias, A., & Moreno, M. P. (2017). Toma de decisiones y rendimiento en las acciones de juego intermedias y finalistas en voleibol , en sets con diferente resultado Decision-making and performance in intermediate and terminal actions in volleyball , according to the set result. *Retos. Nuevas Tendencias En Educación Física, Deporte y Recreación*, *32*(1), 28–33. https://doi.org/10.13140/RG.2.1.4325.0805

Davids, K. (2012). Learning design for Nonlinear Dynamical Movement Systems. *The Open Sports Sciences Journal*, *5*(1), 9–16. https://doi.org/10.2174/1875399X01205010009

Davids, K., Araújo, D., Correia, V., & Vilar, L. (2013). How Small-Sided and Conditioned Games Enhance Acquisition of Movement and Decision-Making Skills. *Exercise and Sport Sciences Reviews*, *41*(3), 154–161. https://doi.org/10.1097/JES.0b013e318292f3ec

Davids, K., Araújo, D., Shuttleworth, R., & Button, C. (2003). Acquiring Skill in Sport: A Constraints-Led Perspective. *International Journal of Computer Science in Sport*, *2*, 31–39.

Davids, K., Bennett, S., Handford, C., & Jones, B. (1999). Acquiring coordination in self-paced, extrinsic timing tasks: A constraints-led perspective. *International Journal of Sport Psychology*. Retrieved from http://apps.webofknowledge.com/full_record.do?product=UA&search_mode=GeneralSearch&qid=45&SID=3FpOgJvwnjJ4yduuMzJ&page=1&doc=1

Davids, K., Bennett, S., & Newell, K. (2006). *Movement System Variability*. Human Kinetics,Champaign, IL.

Fenoglio, R. (2003). *The Manchester United 4 v 4 pilot scheme for U-9"s Part Two: The Analysis. Insight.*

García-Hermoso, A., Dávila-Romero, C., Saavedra, J. M., Garcia-Hermoso, A., & Davila-Romero, C. (2013). Discriminatory Power of Game-Related Statistics in 14-15 Year Age Group Male Volleyball, According To Set. *Perceptual and Motor Skills*, *116*(1), 132–143. https://doi.org/10.2466/03.30.pms.116.1.132-143

Hossener, E.-J., & Wenderoth, N. (2007). Gabriele Wulf: On a attention focus and motor learning. *E-Journal Bewegung Und Training*, *1*(1), 1–64.

Hristovski, R., Davids, K., & Araújo, D. (2006). Affordance-controlled bifurcations of action patterns in martial arts. *Nonlinear Dynamics, Psychology, and Life Sciences*, *10*(4), 409–444. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/16884651

Inkinen, V., Häyrinen, M., & Linnamo, V. (2013). Technical and tactical analysis of women's volleyball. *Biomedical Human Kinetics*, *5*(1), 43–50.

Junior, N. (2013). Evidências científicas sobre os fundamentos do voleibol: importância desse conteúdo para prescrever o treino. *Revista Brasileira de Prescrição e Fisiologia Do Exercício*, *7*(37).

Kelso, J. (1995). *Dynamics patterns: the self-organization of brain and behavior*. Cambridge: MIT Press.

Komar, J., Chow, J.-Y., Chollet, D., & Seifert, L. (2015). Neurobiological degeneracy: supporting stability, flexibility and pluripotentiality in complex motor skill. *Acta Psychologica*, *154*, 26–35. https://doi.org/10.1016/j.actpsy.2014.11.002

Lam, W. K., Maxwell, J. P., & Masters, R. S. W. (2009). Analogy versus explicit learning of a modified basketball shooting task: performance and kinematic outcomes. *Journal of Sports Sciences*, *27*(2), 179–191. https://doi.org/10.1080/02640410802448764

Lee, M. C. Y., Chow, J. Y., Komar, J., Tan, C. W. K., & Button, C. (2014). Nonlinear pedagogy: an effective approach to cater for individual differences in learning a sports skill. *PloS One*, *9*(8), e104744. https://doi.org/10.1371/journal.pone.0104744

Marcelino, R. (2008). Relationship between distribution zone and attack efficacy in elite men ´ s volleyball. In *II CONGRESO INTERNACIONAL DE CIENCIAS DEL DEPORTE*. PONTEVEDRA.

Mesquita, I. (2005). A contextualização do treino no Voleibol: a contribuição do construtivismo. In D. Araújo (Ed.), *A acção táctica no desporto* (pp. 355–378). Visão e Contextos Lda.

Newell, K. (1986). Constraints on the development of coordination. *Motor Development in Children: Aspects of Coordination and Control*. https://doi.org/10.1016/S0166-4115(08)62541-8

Newell, K., & Ranganathan, R. (2010). Instrutcions as constraints in motor skill acquisition. In K. Davids, K. Renshaw, & G. Savelsbergh (Eds.), *Motor Learning in Practice: A Constraints-Led Approach* (pp. 17–32). London: Routledge.

Palao, J.-M., Santos, J., & Urena, A. (2007). Effect of the manner of spoke execution on spike performance in volleyball. *International Journal of Performance Analysis in Sport*, *7*(2), 1999–1999.

Palao, J., Manzanares, P., & Ortega, E. (2009). Techniques used and efficacy of volleyball skills in relation to gender. *International Journal of Performance Analysis in Sport*, 281–293. Retrieved from http://www.ingentaconnect.com/content/uwic/ujpa/2009/00000009/00000002/art00014

Palao, J., Manzanares, P., & Valadés, D. (2015). Way of scoring by Spanish First Division volleyball teams in relation to winning/losing, home/away, final classification, and type of confrontation. *Journal of Human Sport and Exercise*, *10*(1), 36–46.

Passos, P., Araújo, D., Davids, K., Gouveia, L., Serpa, S., Milho, J., & Fonseca, S. (2009). Interpersonal pattern dynamics and adaptive behavior in multiagent neurobiological systems: conceptual model and data. *Journal of Motor Behavior*, *41*(5), 445–459. https://doi.org/10.3200/35-08-061

Paulo, A., Zaal, F. T. J. M., Fonseca, S., & Araújo, D. (2016). Predicting volleyball serve-reception. *Frontiers in Psychology*, *7*(NOV). https://doi.org/10.3389/fpsyg.2016.01694

Paulo, A., Zaal, F. T. J. M., Seifert, L., Fonseca, S., & Araújo, D. (2018). Predicting volleyball serve-reception at group level. *Journal of Sports Sciences*, *36*(22), 2621–2630. https://doi.org/10.1080/02640414.2018.1473098

Pepping, G.-J., & Li2, F.-X. (2000). Changing Action Capabilities and the Perception of Affordances. *Journal of Human Movement Studies*, *39*(September 2015), 115–140.

Rocha, C. M. Da, & Baranti, V. J. (2004). Uma análise dos fatores que influenciam o ataque no voleibol masculino de alto nível. *Revista Brasileira de Educação Física e Esporte*, *8*(4), 303–314.

Schmidt, R. a. R. (1975). A Schema Theory of Discrete Motor Skill Learning. *Psychological Review*, *82*(4), 225–260. https://doi.org/10.1037/h0076770

Schöllhorn, W. Michelbrink, M. Beckmann, H. Trockel, M. Sechelmann, M. Davids, K. (2006). (2006). Does noise provide a basis for the unification of motor learning theories ? *International Journal of Sport Psychology*, *2/3*(February), 34–42.

Schöllhorn, W., Beckmann, H., Janssen, D., & Drepper, J. (2010). Stochastic perturbations in athletic field events enhance skill acquisition. In I. Renshaw, K. Davids, & G. Savelsbergh (Eds.), *Motor learning in practice - A constraints-led approach* (pp. 69–82). Routledge.

Schöllhorn, W. I., & Bauer, H. U. (1998). Idendifying individual movement styles in high performance sports by means of self-organizing kohonen maps. *16. International Symposium on Biomechanics in Sports*, *9*, 574–577.

Seifert, L., Wattebled, L., Herault, R., Poizat, G., Adé, D., Gal-Petitfaux, N., & Davids, K. (2014). Neurobiological degeneracy and affordance perception support functional intra-individual variability of inter-limb coordination during ice climbing. *PloS One*, *9*(2), e89865. https://doi.org/10.1371/journal.pone.0089865

Serra-Olivares, J., & García-Rubio, J. (2017). La problemática táctica, clave en el diseño representativo de tareas desde el enfoque de la pedagogía no lineal aplicada al deporte. *Retos*, *32*, 278–280.

Tan, C. W. K., Chow, J. Y., & Davids, K. (2012). 'How does TGfU work?': examining the relationship between learning design in TGfU and a nonlinear pedagogy. *Physical Education & Sport Pedagogy*, *17*(4), 331–348. https://doi.org/10.1080/17408989.2011.582486

Wu, H. G., Miyamoto, Y. R., Gonzales Castro, L. N., Ölveczky, B. C., & Smith, M. a. (2014). Temporal structure of motor vriability is dynamically regulated and predicts motor learning ability. *Nature Neuroscience*, *17*(2), 312–321. https://doi.org/10.1038/nn.3616

Wulf, G., Lauterbach, B., & Toole, T. (1999). The learning advantages of an external focus of attention in golf. *Research Quarterly for Exercise and Sport*, *70*(2), 120–126. https://doi.org/10.1080/02701367.1999.10608029

2.2 Neurobiological tensegrity: The basis for understanding inter-individual variations in task performance?

Caldeira, P., Davids,K. & Araújo, D. (accepted for publication) Neurobiological tensegrity: The basis for understanding inter-individual variations in task performance? *Human Movement Science*

2.2.1 Abstract:

Bernstein's (1996) levels of movement organization includes tonus, the muscular-contraction level that primes individual movement systems for (re)organizing coordination patterns. The hypothesis has been advanced that the tonus architecture is a multi-fractal tensegrity system, deeply reliant on haptic perception for regulating movement of an individual actor in a specific environment. Further arguments have been proposed that the tensegrity-haptic system is implied in all neurobiological perception and that tensegrity properties can support the formation of interpersonal synergies formed by individuals in (sport) teams. In this position statement we consider whether the musculoskeletal system can be conceptualized as a neurobiological tensegrity system, which supports each individual in co-adapting to such varied contexts of dynamic performance. Evidence for this position, revealed in investigations of judgments of object properties, perceived during manual hefting, is based on each participant's tensegrity. The implication is that the background organizational state of every individual is unique, given that no neurobiological architecture (musculo-skeletal components) is identical. The unique tensegrity of every organism is intimately related to individual differences, channeling individualized adaptations to constraints (task, environment, organismic), which change over different timescales. This neurobiological property assists transitions from one stable state of coordination to another. We conclude by discussing how tensegrity changes over time according to skill acquisition and learning.

Keywords: Tensegrity; neurobiological systems; human movement; individual variations; perception-action; skill acquisition

2.2.2 Introduction

Scientific interest in the nature of specific human-environment interactions has adopted different approaches and relied on varied theorical frameworks to understand how individuals regulate their behaviours (An, 2012; Luu et al., 2004; Warren, 2006). A key applied scientific aim is to unravel generalized laws to explain phenomena and gradually enrich human experiences and conditions. However, despite tendencies for behavioral analyses to be typically based on group average data, this endeavor has paradoxically revealed that individual variation seems to be an important constant in understanding functionality (e.g., Davids, Bennett, & Newell, 2006; Newell & Corcos, 1993). Nonlinearity in motor learning and development has been identified as a key source of the confounding effects of averaging data of participants and trials over time (Davids, Button, & Bennett, 1999; Newell, Liu, & Mayer-Kress, 2001). Here, we suggest how an understanding of the structural basis of neurobiological systems may provide some insights on the origin of such functional variations in movement behaviour. Nikolai Bernstein's work on the levels of movement organization suggests tonus as the muscular-contraction level that supports individual movement systems for (re)organizing coordination patterns (Bernstein, 1996). This background level, supporting the other levels of movement organization, was later hypothesized to possess a multi-fractal tensegrity architecture, predicated on the most significant medium of haptic perception (Turvey & Fonseca, 2014). James Gibson (1979), the founding father of ecological psychology, underscored the prevalence of haptic perception (which he termed 'dynamic touch') in everyday life activities, leading (Turvey et al., 1998) to argue that "the role of dynamic touch in the control of manipulatory activity may be both more continuous and fundamental than that of vision"(p35).

Whereas Bernstein (1996) first suggested the crucial role of a background level of tonus, for action, Gibson (1979) recognized its importance for perception, which Turvey and Fonseca (2014) drew upon to unveil its structure and function. They promoted tensegrity as the proper characterization of the medium for the haptic perceptual system, contrasting with the original conceptualization which was considered a structural-architectural concept. We took Turvey and Fonseca's (2014) view and conceptualized their process of constant structural modulation and reconfiguration as a basis to formally understand and interpret individual differences in movement organization. In this position statement we build upon the aforementioned work and concepts to make the case that tensegrity properties can provide a basis for interpreting inter-individual variation in task performance. Conceptualizing the musculoskeletal system as a neurobiological tensegrity system and its relationship with the individual perception-action coupling provides a starting point to understand individualized variation in regulating goal-directed interactions (Araújo, Davids, & Hristovski, 2006). We first review the nature of tensegrity concepts in neurobiological systems and their relation to human movement, before advancing suggestions how they can form the basis of individual differences in performance.

2.2.3 Tensegrity in neurobiological systems

Tensegrity structures

Fuller (1962), coined the term "tensegrity" to describe structures that maintain their integrity by global tension in neurobiological systems. An important challenge is to consider how tensegrity in neurobiological systems can contribute to understanding individual differences in organization of perception and action. Tensegrity in neurobiological systems is an overall structure (there are structures within structures) with a particular set of properties, and most importantly, is a structure of functional primacy (Turvey, 2007). Functionality supported by tensegrity structures is sustained by their key properties: pre-stress, energetic efficiency, non-linear behaviours and omnidirectional stability. Pre-stress refers to the ongoing intrinsic tension that facilitates adaptability to behavioral changes. Such changes are induced by stress acting anywhere in the tensegrity system, and behavioral adaptability is expressed by changes in the configuration of the tensegrity structure, which spontaneously favor energetic efficiency. When stressed, tensegrity structures become stronger due to non-linear stiffening behaviours, independent of orientation with respect to gravity, maintaining stability in the structure to support system function (Scarr, 2014). Tensegrity in neurobiological systems can be observed at multiple scales, from the molecular dimension (Liedl et al., 2010) to the whole human movement system (Turvey & Fonseca, 2014). Tensegrity is not simply a part of a neurobiological system: it is constitutive of such systems. Ingber's work on embryological development showed that cytoskeleton cells' tensegrity architecture, and the mechanical forces they exert on extracellular matrices, are crucial for tissue pattern formation (Ingber, 2006). At a higher scale of observation, the spine, a structure so fundamental to most neurobiological behaviors, has tensegrity as the basis of its functionality. Conventional models of the spine, based on Newtonian laws, cannot explain the resilience demonstrated when it is subjected to common loads, other than compression, such as when adults pick up a child, or its functional adaptability to different performance environments (e.g., land, sea, air) or the energetic efficiency it exhibits in every action (Levin, 2002).

The haptic system also relies on tensegrity properties to efficiently underpin movement organization and regulation. Like other sensory systems, to propagate information, it requires a medium that needs to be place and direction invariant. Connective tissue in a broader macroscopic sense provides this medium, offering the necessary continuity and invariant properties (Turvey & Fonseca, 2014). Mangalam et al. (2020) showed the involvement of the whole-body tensegrity structure in task performance requiring judgments of object length and heaviness. Participants holding six different experimental objects varying in torque produced, mass and moment of inertia, registered fractal displacement fluctuations in the center of pressure, which all contributed to perceptual judgment of length and heaviness. Also, the fractality in center of pressure displacement increased across trials, highlighting an increased contribution to the perceptual judgment in a body location relatively distal from the hand holding the object (Mangalam et al., 2020). The relationship of haptic perception and movement is highlighted by the correlation of diminished haptic perception with lower motor abilities of children with developmental disorders (Tseng et al., 2019) and patients with Parkinson's disease (Mori et al., 2019). Fractality and complexity in the body are interlinked and ground interdisciplinary approaches in human movement science (Delignières & Marmelat, 2012). Recently, Cabe (2019) expanded on the hypothesis of tensegrity being the basis of all active movement. He made the point that any kind of environmental exploration (looking, listening, tasting, smelling, etc.) involves active movement and, therefore, is bound to engage each individual's tensegrity network.

Human movement and tensegrity

Bernstein's work (1996) on coordination was fundamental to understand how the human movement system solves the degrees of freedom problem. The "infinite" possibilities of combined multi-articular movements (i.e., the degrees of freedom of each joint offer a countless set of possibilities) are reduced by the continuous (re)organization of functional coordinative structures (synergies) that exhibit the necessary consistency and flexibility to meet changing task demands. To Bernstein, the level of tonus (i.e., muscle-contraction level) primes the system to manage the necessary (re)organization of coordination patterns in skill adaptation. Indeed, “the basement level of tone” (Turvey & Fonseca, 2014, p.143) supports the muscular-ligament-skeleton to (re)organize complex movements. In either case, the pre-stress property of tensegrity structures provides system stability and adaptability when under mechanical perturbations.

Tensegrity supports movement production in neurobiological systems by facilitating force transmission (and information), which have to be considered beyond conventional descriptions of muscular-skeleton systems. A whole-body background force transmission system has to include fascia and recognize its role in connecting all other elements. In addition to the well-established process of muscles transmitting force to tendons, myofascial force transmission is another available path to produce joint movement. The relation between sarcomeres and the endomysium (a part of the extracellular matrix) allows myofascia to transmit force that can be placed at intra, extra and inter muscular levels (see Huijing, 2003 for details), driving a more integrative approach to understand the net force responsible for movement (Huijing, 2003). Differences in force between the proximal and distal insertions of a muscle, as well as changes in muscle length, exerting force in tendons of other muscles that are kept constant, corroborate the existence of epimuscular myofascial pathways (Maas & Sandercock, 2010). At the intramuscular scale of analysis, myofascial force transmission to the tendon can occur longitudinally (fasciotendinous transmission) or to the epimysium that surrounds the muscle. Extramuscular force is transmitted between a muscle epimysium and extramuscular connective tissue (e.g., neurovascular tract) and intermuscular force transmission occurs between neighboring muscles through connective tissue linked to the muscle belly (Huijing, 2003; Maas & Sandercock, 2010). Due to the inherent complexity of such a global system, *in situ* studies (Huijing & Baan, 2001; Maas, Baan, & Huijing, 2001; Rijkelijkhuizen, Baan, De Haan, De Ruiter, & Huijing, 2005) have produced more compelling evidence than *in vivo* experiments (Oda et al., 2007; Yaman et al., 2009). However, continuity of the myofascial system and force transmission has been determined in trunk and limbs (Krause et al., 2016; Wilke & Krause, 2019). To express this continuity Myers (1997a, b) proposed a topology of different lines in the body. Myofascial chains are anatomical continuities of muscle and fascia that Myers (1997a, b) named according to their depth, location and role in the human body: Deep Anterior Line (DAL), Superficial Back Line (SBL), Superficial

Anterior Line (SAL), Lateral Line (LL), Spiral Line (SL), Back Functional Line (BFL), Front Functional Line (FFL) and four (deep/superficial and anterior/posterior) Arm Lines (AL). There is strong evidence of the existence of the SBL, BFL, FFL and moderate evidence for the SL and LL (Wilke et al., 2016).

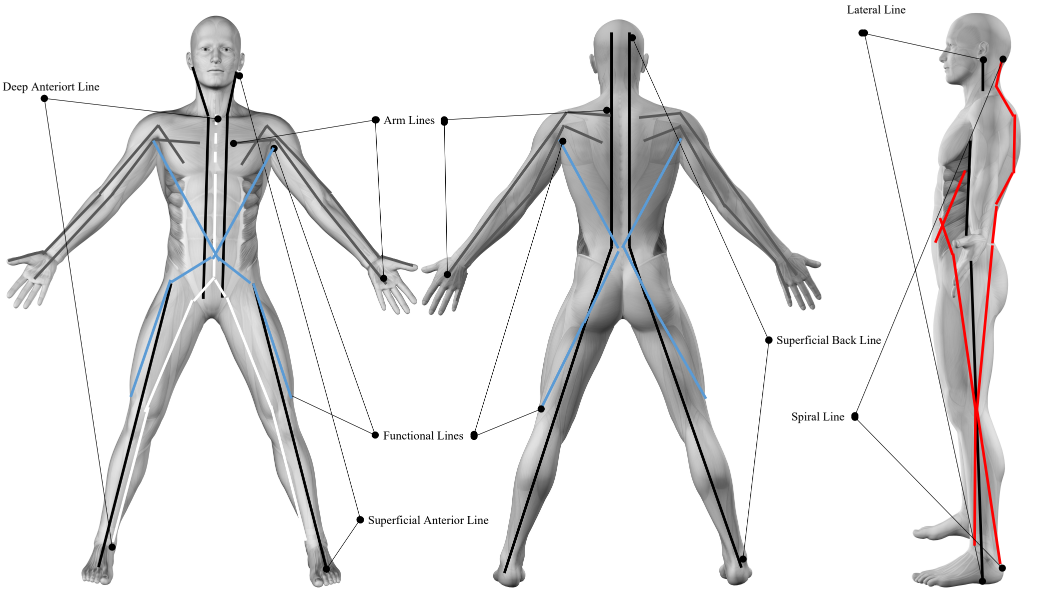


Figure 2. 3 Myofascial chains. Adapted from Myer's Anatomy Trains, 2^a Ed (2006)

Future research is needed not only to consolidate this evidence, and verify the existence of the remaining lines, but also because other studies have confirmed lateral force transmission (Huijing, Maas, & Baan, 2003; Huijing, van de Langenberg, Meesters, & Baan, 2007; Huijing, Yaman, Ozturk, & Yucesoy, 2011; Yucesoy, 2010). Nevertheless, evidence of restored structure functionality (e.g., shoulder and lumbar spine), through manipulation of fascia based on the concept of tensegrity (i.e., manipulation in a different location other than the affected structure), highlights the network connectivity (Grieve et al., 2015; Kassolik et al., 2013). The same approach has been shown to reduce lower back pain (Casato et al., 2019) that in some cases is caused by diminished mechanical properties of fascia (Langevin et al., 2009, 2011). Fascia, specifically fascial disorders, is also linked to a myriad of pathological conditions such as fibromyalgia (Liptan, 2010), lymphedema, deficient thermoregulation, diabetes, and deficient muscle function (Stecco et al., 2016). Taken together, this evidence suggests a relation between a less efficient fascial network and loss of functionality in systems and structures, sometimes accompanied by pain.

Relevant to the topic of individual differences is the variation between participants in studies of fascia structure, location and mechanical properties. For example, in the transition between biceps femoris and the sacrotuberous ligament, a part of Myers superficial back line, high inter-individual variation in force transmission (7-69%) was observed, depending on differences in the sacrotuberous ligament fixation to the ischial tuberosity (van Wingerden et al., 1993). The plantar fascia, also part of the superficial back line, presents heterogenous morphology, locations and mechanical properties between sexes (Shiotani et al., 2019). The transition between adductor longus and the contralateral rectus abdominis, a part of the front functional line, also reveals high variation in mechanical properties among tested organisms (Norton-Old et al., 2013). An experimental study conducted by Kirilova et.al. (2011) on the mechanical properties of human abdominal fascia, part of the superficial anterior line, showed, as a rule, variability among individuals in stress-strain curves and other parameters such as maximal stress, stretch ratio at maximal stress and maximal stretch at rupture (Kirilova et al., 2011). Therefore, mechanical linkages to support coordinative structures is based on a tensegrity architecture and naturally benefits from the set of properties associated with it, however, underpinned by individualized morphologic, structural and functional differences.

2.2.4 Tensegrity and the basis for individualized Perception-Action

Tensegrity enables perception by priming and facilitating force transmission for individual interactions with the environment. From an ecological dynamics perspective of perception-action coupling at the level of the performer-environment system (Araújo et al., 2006), tensegrity has to play a role in regulating goal-directed actions in specific performance environments. It has a significant role in synergy formation during adaptive behaviour. This can be evidenced by space travel data from long term exploratory journeys revealing how healthy individuals subjected to altered haptic perception exhibit poorer motor performance in skilled manual tasks. In microgravity (i.e., near zero gravity) conditions, there is less pressure and load on the body. These changing gravitational effects, in turn, reduce the contribution of haptic perception, with visible detriments in regulating actions such as aiming movements, tracking, grasping and complex movements. In microgravity, with practice, astronauts make adjustments to movements that reduce error, but adaption is never completed (Ross, 2008). From an ecological dynamics perspective, synergies express the cooperation among component interactions to achieve an intended task-goal, retaining a context-dependent and structure-function relation (Profeta & Turvey, 2018). Ecological dynamics also implies a reciprocity and continuity of perception and action, with tensegrity architecture supporting self-organized coordination tendencies through both processes. Synergies are patterned organizations of system components that, if necessary, can participate in other organized coordination patterns with the same or different functions (Turvey, 2007).

Tensegrity is essential to movement in neurobiological systems, because it provides structural stability that enables the system to exhibit tendencies for degeneracy and metastability, hallmarks of adaptive behaviour. Degeneracy in neurobiological systems is a property indicating that the same output function can be achieved by structural variations in motor behaviour (Seifert et al., 2016). Degeneracy (like tensegrity) is present at every scale of biological organization, including: (i) the level of genetic code (Edelman & Gally, 2001), (ii) muscular-skeletal functioning (Dickinson et al., 2000), (iii) neural-network activation (Kelso, 2012), and (iv), whole-body complex movements (Seifert et al., 2014), For example, longitudinal data on infants' brain activity responses to looming-danger showed an intra-trial dynamic (re)organization of connectivity patterns consistent with degeneracy (van der Weel et al., 2019). The investigation focused on group differences between infants aged between 5-6 months and 12-13 months. Data presented revealed individual differences in looming-related visual evoked-potential responses and brain activity at the dipole visual cortex midline. In complex motor skills such as ice climbing, when compared to novices, experts show a more efficient performer-environment coupling (i.e., adaptive behaviour) that is predicated on a higher degree of degeneracy based on participants' perception of climbing affordances (Seifert et al., 2014). Evidence for this idea was provided by Hong and Newell (2006). They asked novices to learn a new coordination task on a ski simulator, expressing successful performance either by in-phase or anti-phase coupling between angular motion of the simulator and the learners' center of mass (COM) in the horizontal plane. Data revealed that, while maintaining performer-environment coupling, learners used different joint movement relations (i.e., exploiting system degeneracy) to achieve successful performance outcomes. Hong and Newell (2006) concluded that the role of freezing and freeing proposed by Bernstein (1996) on movement coordination is predicated not only in the intertwined relations between task, individual and environmental constraints, but also in inter-individual variations of search strategy in the perceptual-motor workspace.

Another important neurobiological property, metastability, may emerge when a system is placed under a set of specific task constraints, requiring it to perform under the influence of more than one system attractors, or in the present case, performance solutions (Kelso, 2012). A metastable state allows a neurobiological system to exploit degeneracy as the situation unfolds, which is common in dynamic complex environments. Metastability was earlier reported in an investigation of performance in a rhythmic bimanual coordination task (Jeka & Kelso, 1995), and has also been observed in more complex movement tasks (Davids & Araújo, 2010). Hristovski et al. (2006) showed that boxers performing a heavy bag punching task exploited inherent system degeneracy at a specific distance determined by the ratio of the distance to the target and the arm length of the participants. However, at shorter and longer distances, only one performance solution (attractor) emerged (Hristovski et al., 2006). In another sport task, cricket batting, task constraints manipulation also helped identify a metastable region of movement coordination tendencies. Manipulating ball bouncing location to correspond to four different regions when facing cricket bowling, movement timing and performance outcomes of batters were analyzed. Evidence revealed stable movement patterns in three regions and also one metastable region where highly diverse movement solutions emerged in batters (coordinating front foot and back foot hitting actions without directive instructions) to enhance performance functionality (Pinder et al., 2012).

The emergent actions of the individuals (boxers and batters) in these examples from sport performance are context-dependent and mediated by interactions with their intentionality (Araújo, Hristovski, Seifert, Carvalho, & Davids, 2017). The (re)organization of actions is based on the continuous coupling of perception and action provided by structures that exhibit tensegrity properties. Emergent movement solutions in metastable regions of performance are not identical for all performers, nor are they infinite (Rein et al., 2010). Thus, the number of simultaneous attractors and transitions between actions may be constrained by the structures responsible for perception-action. When performing the same complex task, skilled athletes exhibit metastability, which contrasts with performance of less skilled athletes. This observation indicates that metastability results from continuous perceptual motor adaptations that can be trained and developed with practice (Pinder et al., 2012; Komar et al., 2014, 2015). Nevertheless, even skilled athletes show inter-individual variability in metastability regions in complex motor tasks (Rein et al., 2010).

2.2.5 Tensegrity and individual differences in performance

For tensegrity to provide a basis for understanding variations in individual-environment interactions, two concepts must be reconciled: homogeneity and individuality. The broader conceptualization of the neuro-muscular-fascial-skeleton system, as a multifractal tensegrity structure, provides homogeneity (i.e., a uniform structure and composition throughout). This perspective has indicated that a tensegrity structure is dynamically sustained by properties of pre-stress, energetic efficiency, nonlinear stiffening behaviour and omnidirectional stability (i.e., maintains functional properties independently of gravity direction). Neurobiological individuality remains within the scope of a larger ongoing debate between philosophers and biologists. The question of what constitutes 'individuality' is still the subject of reflection (Pradeu, 2016), as well as how individuality should be conceptualized to address different behavioral questions (Love, 2015). Some conceptualizations of biological individuality are restricted to the performer, but here we focus on those that conceive individual behavior as inseparable from the environmental performance circumstances (Smith-Ferguson & Beekman, 2019). As mentioned, tensegrity is mostly a functional concept (Turvey, 2007), but structure and function are complementary (Kelso & Engstrom, 2006), in that the structure of initial conditions (with specific reference to organismic constraints) informs functional behaviors. The most basic form of structure variation is anatomical. Anatomical variation in the human movement system has been reported in: (i) muscles from head and neck (Harry et al., 1997), (ii) upper (Soubhagya et al., 2008) and lower limbs (Willan et al., 1990) and pelvis (Matejčík, 2010), (iii) the skeleton (Yoshioka et al., 1987), nerves (Adkison et al., 1991) and fascia (Stecco et al., 2013). Fascia has been classified according to its depth in the human body. Superficial fascia is a thin loose connective tissue that often separates anatomical structures, while deep fascia is dense connective tissue (Stecco et al., 2008). Guimberteau (2001, 2010) established the connection between the different layers with an impressive video analysis of a gliding system, a space filled with a vascularized collagen network that connects superficial and deep fascia. This network connects deeper and superficial tissue, allowing them to function differently and having a high proteoglycan content that behaves like a gel. This neurobiological property can only be observed in live or fresh tissue, and is, therefore, beyond the anatomical analysis usually performed in cadavers (Guimberteau, 2001; Guimberteau, Delage, McGrouther, & Wong, 2010).

With regards to inter-individual variations in movement performance, the whole-body tissue network that senses deformation and connects multiple layers of different structures has a chaotic cell arrangement, replete with non-linear behaviors. Therefore, the biophysics of behavior analysis needs to be grounded on methods different from those applied in engineering. To that intent, Muller (1996) explored the dynamics of a planar four-bar linkages system, suited to classify the complexity of biological movement. Although the human body has more complex structures than a four-bar linkages system, it was possible to capture changes in the bars' length in relation to the global geometry of the structure. The dynamics of the model (Muller, 1996) resonates with the aforementioned synergetic properties and tensegrity structures functioning, including: i) non-linear relations between structure shape and kinematic transmission parameters to obtain the most energetically-efficient mechanical behavior; and ii), the same mechanical properties available under different structure morphologies (Levin, de Solórzano, & Scarr, 2017). In sum, these properties *"permits a decoupling between morphologic diversity and function"* (Levin et al, 2017, p. 670), but paradoxically also allows the expression of individuality of the performer in the relation with the dynamical constraints of a particular performance environment. Considering the uniqueness of the myofascial system, based on tensegrity properties that supports the emergence of individual synergetic behaviors, it can be argued that the kinematics of a complex global movement form the observable expression of individuality within a specific context. Individuality in global movements has been observed in gait (Nixon et al., 1999), running (Yam et al., 2004), playing musical instruments (Albrecht et al., 2014; Slater, 2020) and sport movements (Horst et al., 2020).

In goal-directed movement an individual's decisions emerge from the interaction of constraints (individual, task and environmental) and is grounded on the perception-action coupling process (Araújo et al., 2006). The individual's tensegrity network will be at the core of perception and action and "structure individuality", in terms of how it is expressed in a dynamic performance environment. This idea is key in an ecological dynamics perspective of skill learning (Davids, Araújo, Shuttleworth, & Button, 2003), suggesting that each individual performer needs to explore relevant system degrees of freedom (organismic and environmental) to discover which information variables are suitable to achieve a task solution. The relation between system interconnectivity and dexterity of action has been previously hypothesized (see, Harrison & Stergiou, 2015, for details), however, future research needs to ascertain whether, with familiarity and experience, the individual's tensegrity network evolves to satisfy emerging task constraints. The individualized and global nature of the network guides future research to investigating a context-dependent framework and, whether focused on groups or individuals, towards more functional (Woody, 2015) rather than mechanistic (Fagan, 2015) scientific explanations. As the individual performer becomes "attuned" to task-relevant sources of information, task solutions emerge, constrained by an increasingly efficient tensegrity system. Interestingly, skilled athletes often present similar fitness levels to less skilled athletes (Chaabène et al., 2012.; Schaal et al., 2013). Contrary to a linear generalization, faster sprinters are not those with higher joint angular velocity or those applying greater amounts of force onto the supporting ground (Morin et al., 2011), but those who move faster over a certain distance. However, the skilled individual is able to exploit the perceptual-motor degrees of freedom to achieve multiple solutions to the same task goal, exploiting system degeneracy congruent with a "fine-tuned" tensegrity network supporting perception-action. In this process of skill learning, the tensegrity system does its "job", explaining individual performance differences, based on its structural uniqueness.

2.3.5 Conclusion

In this position statement, we considered how the structure-function relationship in movement (re)organization in motor learning supports individual variations in skill development and performance. We considered whether the whole-body tensegrity system has a crucial role in establishing perception-action relations and needs to be considered for understanding the emergence of individual self-regulating trajectories in performance and development of learners over time. The tensegrity system, and the set of properties it encapsulates (pre-stress, energetic efficiency, nonlinear stiffening behaviour and gravity omnidirectionality), is an important medium for haptic perception (Turvey & Fonseca, 2014), being engaged in all exploratory actions (Cabe, 2019). It is also a fundamental part of force transmission that supports joint movements through a continuous and homogeneous distribution of myofascial tissue (Maas & Sandercock, 2010). Functionally adaptive behaviors emerge due to the tensegrity network's capacity for degeneracy and the fluid transition among multiple system states or organization (meta-stability), which promote exploration, discovery and exploitation of different movement solutions. Such a structure exists in all individuals (Muller, 1996), but it is also unique for each individual, and this uniqueness shapes functionality in performer-environment systems. Further research is needed to discover more information on the novel concept of neurobiological tensegrity systems, not only on its properties, but also on discovering its trainability and exploitation for human learning, performance and skill development across the life course.

2.2.7 References:

Adkison, D. P., Bosse, M. J., Gaccione, D. R., & Gabriel, K. R. (1991). Anatomical variations in the course of the superficial peroneal nerve. *Journal of Bone and Joint Surgery - Series A*. https://doi.org/10.2106/00004623-199173010-00014

Albrecht, S., Janssen, D., Quarz, E., Newell, K. M., & Schöllhorn, W. I. (2014). Individuality of movements in music - Finger and body movements during playing of the flute. *Human Movement Science*. https://doi.org/10.1016/j.humov.2014.03.010

An, L. (2012). Modeling human decisions in coupled human and natural systems: Review of agent-based models. *Ecological Modelling*. https://doi.org/10.1016/j.ecolmodel.2011.07.010

Araújo, D., Hristovski, R., Seifert, L., Carvalho, J., & Davids, K. (2017). Ecological cognition: Expert decision-making behaviour in sport. *International Review of Sport and Exercise Psychology.*, 1-25. https://doi.org/DOI: 10.1080/1750984X.2017.1349826

Araújo, D., Davids, K., & Hristovski, R. (2006). The ecological dynamics of decision making in sport. *Psychology of Sport and Exercise*, *7*(6), 653–676. https://doi.org/10.1016/j.psychsport.2006.07.002

Bernstein, N. A. (1996). On the construction of movements. In M. L. Latash & M. T. Turvey (Eds.), *On dexterity and its development*. Mahwah, NJ: Erlbaum. https://doi.org/10.1007/s13398-014-0173-7.2

Cabe, P. A. (2019). All Perception Engages the Tensegrity-Based Haptic Medium. In *Ecological Psychology*. https://doi.org/10.1080/10407413.2018.1526037

Casato, G., Stecco, C., & Busin, R. (2019). Fasciae and nonspecific low back pain Role of fasciae in nonspecific low back pain. In *Eur J Transl Myol* (Vol. 29, Issue 3). www.3bscientific.com

Chaabène, H., Hachana, Y., Franchini, E., Mkaouer, B., & Chamari, K. (2012). *Physical and Physiological Profile of Elite Karate Athletes*.

Davids, K., Bennett, S. J., & Newell, K. M. (2006). *Variability in the movement system: A multi-disciplinary perspective*. Human Kinetics,Champaign, IL.

Davids, K., & Araújo, D. (2010). The concept of "Organismic Asymmetry" in sport science. *Journal of Science and Medicine in Sport*, *13*(6), 633–640. https://doi.org/10.1016/j.jsams.2010.05.002

Davids, K., Araújo, D., Shuttleworth, R., & Button, C. (2003). Acquiring Skill in Sport: A Constraints-Led Perspective. *International Journal of Computer Science in Sport*, *2*, 31–39.

Davids, K., Button, C., & Bennett, S. (1999). Modeling Human Motor Systems in Nonlinear Dynamics: Intentionality and Discrete Movement Behaviors. *Nonlinear Dynamics, Psychology, and Life Sciences*. https://doi.org/10.1023/A:1022429522099

Delignières, D., & Marmelat, V. (2012). Fractal fluctuations and complexity: Current debates and future challenges. *Critical Reviews in Biomedical Engineering*, *40*(6). https://doi.org/10.1615/CritRevBiomedEng.2013006727

Dickinson, M. H., Farley, C. T., Full, R. J., Koehl, M. A. R., Kram, R., & Lehman, S. (2000). How animals move: An integrative view. In *Science*. https://doi.org/10.1126/science.288.5463.100

Edelman, G. M., & Gally, J. A. (2001). Degeneracy and complexity in biological systems. *Proceedings of the National Academy of Sciences of the United States of America*. https://doi.org/10.1073/pnas.231499798

Fagan, M. B. (2015). Collaborative explanation and biological mechanisms. *Studies in History and Philosophy of Science Part A*. https://doi.org/10.1016/j.shpsa.2015.03.004

Fuller, R. (1962). *Tensile-integrity structures.* (Patent No. 3,063,521).

Gibson, J. J. (1979). The Ecological Approach to Visual Perception. In *Houghton Mifflin-Boston*.

Grieve, R., Goodwin, F., Alfaki, M., Bourton, A. J., Jeffries, C., & Scott, H. (2015). The immediate effect of bilateral self myofascial release on the plantar surface of the feet on hamstring and lumbar spine flexibility: A pilot randomised controlled trial. *Journal of Bodywork and Movement Therapies*, *19*(3). https://doi.org/10.1016/j.jbmt.2014.12.004

Guimberteau, J. (2001). How is the anatomy adopted for tendon sliding? In J. Guimberteau (Ed.), *New ideas in hand flexor tendon surgery.* (pp. 47–90). Aquitaine Domaine Forestier.

Guimberteau, J. C., Delage, J. P., McGrouther, D. a, & Wong, J. K. F. (2010). The microvacuolar system: how connective tissue sliding works. *The Journal of Hand Surgery, European Volume*, *35*(8), 614–622. https://doi.org/10.1177/1753193410374412

Harrison, S. J., & Stergiou, N. (2015). Complex adaptive behavior and dexterous action. *Nonlinear Dynamics, Psychology, and Life Sciences*, *19*(4).

Harry, W. G., Bennett, J. D. C., & Guha, S. C. (1997). Scalene muscles and the brachial plexus: Anatomical variations and their clinical significance. *Clinical Anatomy*. https://doi.org/10.1002/(SICI)1098-2353(1997)10:4<250::AID-CA6>3.0.CO;2-W

Hong, S. L., & Newell, K. M. (2006). Practice effects on local and global dynamics of the ski-simulator task. *Experimental Brain Research*. https://doi.org/10.1007/s00221-005-0145-4

Horst, F., Janssen, D., Beckmann, H., & Schöllhorn, W. I. (2020). Can Individual Movement Characteristics Across Different Throwing Disciplines Be Identified in High-Performance Decathletes? *Frontiers in Psychology*. https://doi.org/10.3389/fpsyg.2020.02262

Hristovski, R., Davids, K., Araújo, D., & Button, C. (2006). How boxers decide to punch a target: Emergent behaviour in nonlinear dynamical movement systems. *Journal of Sports Science and Medicine*, *5*(CSSI-1), 60–73.

Huijing, P. A., & Baan, G. C. (2001). Myofascial Force Transmission Causes Interaction between Adjacent Muscles and Connective Tissue: Effects of Blunt Dissection and Compartmental Fasciotomy on Length Force Characteristics of Rat Extensor Digitorum Longus Muscle. *Archives of Physiology and Biochemistry*. https://doi.org/10.1076/apab.109.2.97.4269

Huijing, P. A. (2003). Muscular force transmission necessitates a multilevel integrative approach to the analysis of function of skeletal muscle. In *Exercise and Sport Sciences Reviews*. https://doi.org/10.1097/00003677-200310000-00003

Huijing, P. A., Maas, H., & Baan, G. C. (2003). Compartmental fasciotomy and isolating a muscle from neighboring muscles interfere with myofascial force transmission within the rat anterior crural compartment. *Journal of Morphology*. https://doi.org/10.1002/jmor.10097

Huijing, P. A., van de Langenberg, R. W., Meesters, J. J., & Baan, G. C. (2007). Extramuscular myofascial force transmission also occurs between synergistic muscles and antagonistic muscles. *Journal of Electromyography and Kinesiology*. https://doi.org/10.1016/j.jelekin.2007.02.005

Huijing, P. A., Yaman, A., Ozturk, C., & Yucesoy, C. A. (2011). Effects of knee joint angle on global and local strains within human triceps surae muscle: MRI analysis indicating in vivo myofascial force transmission between synergistic muscles. *Surgical and Radiologic Anatomy*, *33*(10), 869–879. https://doi.org/10.1007/s00276-011-0863-1

Ingber, D. E. (2006). Mechanical control of tissue morphogenesis during embryological development. *International Journal of Developmental Biology*, *50*(2–3), 255–266. https://doi.org/10.1387/ijdb.052044di

Jeka, J. J., & Kelso, J. A. S. (1995). Manipulating Symmetry in the Coordination Dynamics of Human Movement. *Journal of Experimental Psychology: Human Perception and Performance*. https://doi.org/10.1037/0096-1523.21.2.360

Kassolik, K., Andrzejewski, W., Brzozowski, M., Wilk, I., Górecka-Midura, L., Ostrowska, B., Krzyzanowski, D., & Kurpas, D. (2013). Comparison of massage based on the tensegrity principle and classic massage in treating chronic shoulder pain. *Journal of Manipulative and Physiological Therapeutics*, *36*(7), 418–427. https://doi.org/10.1016/j.jmpt.2013.06.004

Kelso, J. A. (2012). Multistability and metastability: Understanding dynamic coordination in the brain. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *367*(1591), 906–918. https://doi.org/10.1098/rstb.2011.0351

Kelso, J. A., & Engstrom, D. A. (2006). *The Complementary Nature*. Massachusets Institute of Technology.

Kirilova, M., Stoytchev, S., Pashkouleva, D., & Kavardzhikov, V. (2011). Experimental study of the mechanical properties of human abdominal fascia. *Medical Engineering and Physics*. https://doi.org/10.1016/j.medengphy.2010.07.017

Komar, J., Chow, J. Y., Chollet, D., & Seifert, L. (2015). Neurobiological degeneracy: Supporting stability, flexibility and pluripotentiality in complex motor skill. *Acta Psychologica*, *154*, 26–35. https://doi.org/10.1016/j.actpsy.2014.11.002

Komar, J., Sanders, R. H., Chollet, D., & Seifert, L. (2014). Do qualitative changes in interlimb coordination lead to effectiveness of aquatic locomotion rather than efficiency? *Journal of Applied Biomechanics*, *30*(2). https://doi.org/10.1123/jab.2013-0073

Krause, F., Wilke, J., Vogt, L., & Banzer, W. (2016). Intermuscular force transmission along myofascial chains: A systematic review. In *Journal of Anatomy*. https://doi.org/10.1111/joa.12464

Langevin, H. M., Fox, J. R., Koptiuch, C., Badger, G. J., Greenan- Naumann, A. C., Bouffard, N. A., Konofagou, E. E., Lee, W. N., Triano, J. J., & Henry, S. M. (2011).

Reduced thoracolumbar fascia shear strain in human chronic low back pain. *BMC Musculoskeletal Disorders*, *12*. https://doi.org/10.1186/1471-2474-12-203

Langevin, H. M., Stevens-Tuttle, D., Fox, J. R., Badger, G. J., Bouffard, N. A., Krag, M. H., Wu, J., & Henry, S. M. (2009). Ultrasound evidence of altered lumbar connective tissue structure in human subjects with chronic low back pain. *BMC Musculoskeletal Disorders*, *10*(1). https://doi.org/10.1186/1471-2474-10-151

Levin, S. (2002). The tensegrity-truss as a model for spine mechanics: biotensegrity. *Journal of Mechanics in Medicine and Biology*, *02*(03n04), 375–388. https://doi.org/10.1142/S0219519402000472

Levin, Stephen, de Solórzano, S. L., & Scarr, G. (2017). The significance of closed kinematic chains to biological movement and dynamic stability. *Journal of Bodywork and Movement Therapies*. https://doi.org/10.1016/j.jbmt.2017.03.012

Liedl, T., Högberg, B., Tytell, J., Ingber, D. E., & Shih, W. M. (2010). Self-assembly of three-dimensional prestressed tensegrity structures from DNA. *Nature Nanotechnology*, *5*(7), 520–524. https://doi.org/10.1038/nnano.2010.107

Liptan, G. L. (2010). Fascia: A missing link in our understanding of the pathology of fibromyalgia. *Journal of Bodywork and Movement Therapies*, *14*(1), 3–12. https://doi.org/10.1016/j.jbmt.2009.08.003

Love, A. C. (2015). Collaborative explanation, explanatory roles, and scientific explaining in practice. *Studies in History and Philosophy of Science Part A*. https://doi.org/10.1016/j.shpsa.2015.03.003

Luu, P., Tucker, D. M., & Makeig, S. (2004). Frontal midline theta and the error-related negativity: Neurophysiological mechanisms of action regulation. *Clinical Neurophysiology*. https://doi.org/10.1016/j.clinph.2004.03.031

Maas, H., Baan, G. C., & Huijing, P. A. (2001). Intermuscular interaction via myofascial force transmission: Effects of tibialis anterior and extensor hallucis longus length on force transmission from rat extensor digitorum longus muscle. *Journal of Biomechanics*. https://doi.org/10.1016/S0021-9290(01)00055-0

Maas, H., & Sandercock, T. G. (2010). Force transmission between synergistic skeletal muscles through connective tissue linkages. In *Journal of Biomedicine and Biotechnology*. https://doi.org/10.1155/2010/575672

Mangalam, M., Chen, R., McHugh, T. R., Singh, T., & Kelty-Stephen, D. G. (2020). Bodywide fluctuations support manual exploration: Fractal fluctuations in posture predict perception of heaviness and length via effortful touch by the hand. *Human Movement Science*. https://doi.org/10.1016/j.humov.2019.102543

Matejčík, V. (2010). Anatomical variations of lumbosacral plexus. *Surgical and Radiologic Anatomy*. https://doi.org/10.1007/s00276-009-0546-3

Mori, L., Putzolu, M., Bonassi, G., Galeoto, G., Mezzarobba, S., Trompetto, C., Avanzino, L., Marchese, R., Abbruzzese, G., & Pelosin, E. (2019). Haptic perception of verticality correlates with postural and balance deficits in patients with Parkinson's disease. *Parkinsonism and Related Disorders*, *66*, 45–50. https://doi.org/10.1016/j.parkreldis.2019.06.026

Morin, J. B., Edouard, P., & Samozino, P. (2011). Technical ability of force application as a determinant factor of sprint performance. *Medicine and Science in Sports and Exercise*, *43*(9). https://doi.org/10.1249/mss.0b013e318216ea37

Muller, M. (1996). A novel classification of planar four-bar linkages and its application to the mechanical analysis of animal systems. *Philosophical Transactions of the Royal Society B: Biological Sciences*. https://doi.org/10.1098/rstb.1996.0065

Myers, T. W. (1997a). The "anatomy trains": part 1. *Journal of Bodywork and Movement Therapies*. https://doi.org/10.1016/S1360-8592(97)80010-1

Myers, T. W. (1997b). The "anatomy trains": part 2. *Journal of Bodywork and Movement Therapies*. https://doi.org/10.1016/S1360-8592(97)80031-9

Newell, K. M., & Corcos, D. M. (1993). Issues in variability and motor control. In K. Newell & Corcos DM (Eds.), *Variability and motor control.* (pp. 1–12). Human Kinetics,Champaign, IL.

Newell, K. M., Liu, Y. T., & Mayer-Kress, G. (2001). Time scales in motor learning and development. *Psychological Review*, *108*(1), 57–82. https://doi.org/10.1037//0033-295X

Nixon, M. S., Carter, J. N., Nash, J. M., Huang, P. S., Cunado, D., & Stevenage, S. V. (1999). Automatic gait recognition. *IEE Colloquium (Digest)*. https://doi.org/10.1007/0-306-47044-6_11

Norton-Old, K. J., Schache, A. G., Barker, P. J., Clark, R. A., Harrison, S. M., & Briggs, C. A. (2013). Anatomical and mechanical relationship between the proximal attachment of adductor longus and the distal rectus sheath. *Clinical Anatomy*. https://doi.org/10.1002/ca.22116

Oda, T., Kanehisa, H., Chino, K., Kurihara, T., Nagayoshi, T., Fukunaga, T., & Kawakami, Y. (2007). In vivo behavior of muscle fascicles and tendinous tissues of human gastrocnemius and soleus muscles during twitch contraction. *Journal of Electromyography and Kinesiology*. https://doi.org/10.1016/j.jelekin.2006.04.013

Pinder, R., Davids, K., & Renshaw, I. (2012). Metastability and emergent performance of dynamic interceptive actions. *Journal of Science and Medicine in Sport*, *15*(5), 437–443. https://doi.org/10.1016/j.jsams.2012.01.002

Pradeu, T. (2016). The many faces of biological individuality. In *Biology and Philosophy*. https://doi.org/10.1007/s10539-016-9553-z

Profeta, V. L. S., & Turvey, M. T. (2018). Bernstein's levels of movement construction: A contemporary perspective. *Human Movement Science*, *57*(December 2017), 111–133. https://doi.org/10.1016/j.humov.2017.11.013

Rein, R., Davids, K., & Button, C. (2010). Adaptive and phase transition behavior in performance of discrete multi-articular actions by degenerate neurobiological systems. *Experimental Brain Research*, *201*(2), 307–322. https://doi.org/10.1007/s00221-009-2040-x

Rijkelijkhuizen, J. M., Baan, G. C., De Haan, A., De Ruiter, C. J., & Huijing, P. A. (2005). Extramuscular myofascial force transmission for in situ rat medial gastrocnemius and plantaris muscles in progressive stages of dissection. *Journal of Experimental Biology*. https://doi.org/10.1242/jeb.01360

Ross, H. E. (2008). Haptic perception in space travel. In *Human Haptic Perception: Basics and Applications*. https://doi.org/10.1007/978-3-7643-7612-3_22

Scarr, G. (2014). *Biotensegrity: The structural basis of life*. Handspring Publishing.

Schaal, M., Ransdell, L. B., Simonson, S. R., & Gao, Y. (2013). Physiologic performance test differences in female volleyball athletes by competition level and player position. *Journal of Strength and Conditioning Research*, *27*(7). https://doi.org/10.1519/JSC.0b013e31827361c4

Seifert, L., Komar, J., Araújo, D., & Davids, K. (2016). Neurobiological degeneracy: A key property for functional adaptations of perception and action to constraints. *Neuroscience and Biobehavioral Reviews*, *69*, 159–165. https://doi.org/10.1016/j.neubiorev.2016.08.006

Seifert, L., Wattebled, L., Herault, R., Poizat, G., Adé, D., Gal-Petitfaux, N., & Davids, K. (2014). Neurobiological degeneracy and affordance perception support functional intra-individual variability of inter-limb coordination during ice climbing. *PloS One*, *9*(2), e89865. https://doi.org/10.1371/journal.pone.0089865

Shiotani, H., Yamashita, R., Mizokuchi, T., Naito, M., & Kawakami, Y. (2019). Site- and sex-differences in morphological and mechanical properties of the plantar fascia: A supersonic shear imaging study. *Journal of Biomechanics*. https://doi.org/10.1016/j.jbiomech.2019.01.014

Slater, P. (2020). The Dark Pattern: Towards a constraints-led approach to jazz trumpet*.* PhD thesis, Sydney Conservatorium of Music, University of Sydney, Australia.

Smith-Ferguson, J., & Beekman, M. (2019). Can't see the colony for the bees: behavioural perspectives of biological individuality. *Biological Reviews*. https://doi.org/10.1111/brv.12542

Soubhagya, R. N., Ashwin, K., Madhan, K. S. J., Latha, V. P., Vasudha, S., & Merin, M. T. (2008). Four-headed biceps and triceps brachii muscles, with neurovascular variation. *Anatomical Science International*. https://doi.org/10.1111/j.1447-073X.2007.00171.x

Stecco, A., Stern, R., Fantoni, I., de Caro, R., & Stecco, C. (2016). Fascial Disorders: Implications for Treatment. In *PM and R* (Vol. 8, Issue 2, pp. 161–168). Elsevier Inc. https://doi.org/10.1016/j.pmrj.2015.06.006

Stecco, C., Porzionato, A., Lancerotto, L., Stecco, A., Macchi, V., Ann Day, J., & De Caro, R. (2008). Histological study of the deep fasciae of the limbs. *Journal of Bodywork and Movement Therapies*. https://doi.org/10.1016/j.jbmt.2008.04.041

Stecco, C., Tiengo, C., Stecco, A., Porzionato, A., Macchi, V., Stern, R., & De Caro, R. (2013). Fascia redefined: Anatomical features and technical relevance in fascial flap surgery. In *Surgical and Radiologic Anatomy*. https://doi.org/10.1007/s00276-012-1058-0

Tseng, Y. T., Holst-Wolf, J. M., Tsai, C. L., Chen, F. C., & Konczak, J. (2019). Haptic perception is altered in children with developmental coordination disorder. *Neuropsychologia*, *127*. https://doi.org/10.1016/j.neuropsychologia.2019.02.004

Turvey, M. T. (2007). Action and perception at the level of synergies. *Human Movement Science*, *26*(4), 657–697. https://doi.org/10.1016/j.humov.2007.04.002

Turvey, M. T., Burton, G., Amazeen, E. L., Butwill, M., & Carello, C. (1998). Perceiving the Width and Height of a Hand-Held Object by Dynamic Touch. *Journal of Experimental Psychology: Human Perception and Performance*. https://doi.org/10.1037/0096-1523.24.1.35

Turvey, M. T., & Fonseca, S. T. (2014). The Medium of Haptic Perception: A Tensegrity Hypothesis. *Journal of Motor Behavior*, *46*(3), 143–187. https://doi.org/10.1080/00222895.2013.798252 van der Weel, F. R. (Ruud), Agyei, S. B., & van der Meer, A. L. H. (2019). Infants' Brain Responses to Looming Danger: Degeneracy of Neural Connectivity Patterns. *Ecological Psychology*. https://doi.org/10.1080/10407413.2019.1615210

van Wingerden, J. P., Vleeming, A., Snijders, C. J., & Stoeckart, R. (1993). A functional-anatomical approach to the spine-pelvis mechanism: interaction between the biceps femoris muscle and the sacrotuberous ligament. *European Spine Journal*. https://doi.org/10.1007/BF00301411

Warren, W. H. (2006). The dynamics of perception and action. *Psychological Review*, *113*(2), 358–389. https://doi.org/10.1037/0033-295X.113.2.358

Wilke, J., & Krause, F. (2019). Myofascial chains of the upper limb: A systematic review of anatomical studies. In *Clinical Anatomy*. https://doi.org/10.1002/ca.23424

Wilke, J., Krause, F., Vogt, L., & Banzer, W. (2016). What is evidence-based about myofascial chains: A systematic review. In *Archives of Physical Medicine and Rehabilitation*. https://doi.org/10.1016/j.apmr.2015.07.023

Willan, P. L., Mahon, M., & Golland, J. A. (1990). Morphological variations of the human vastus lateralis muscle. *Journal of Anatomy*.

Woody, A. I. (2015). Re-orienting discussions of scientific explanation: A functional perspective. *Studies in History and Philosophy of Science Part A*. https://doi.org/10.1016/j.shpsa.2015.03.005

Yam, C. Y. C. Y., Nixon, M. S., & Carter, J. N. (2004). Automated person recognition by walking and running via model-based approaches. *Pattern Recognition*. https://doi.org/10.1016/j.patcog.2003.09.012

Yaman, M., Ledesma-Carbayo, G., Baan, C., Huijing, P. A., Yucesoy, C. A., & Ozturk, C. (2009). MRI assesment of passive muscular-mechanics in vivo using intensity based non-rigid B-spline registration: effects of epimuscular myofascial force transmission. *17th International Society for Magnetic Resonance in Medicine Scientific Meeting & Exhibition*.

Yoshioka, Y., Siu, D., & Cooke, T. D. V. (1987). The anatomy and functional axes of the femur. *Journal of Bone and Joint Surgery - Series A*. https://doi.org/10.2106/00004623-198769060-00012

Yucesoy, C. A. (2010). Epimuscular myofascial force transmission implies novel principles for muscular mechanics. *Exercise and Sport Sciences Reviews*. https://doi.org/10.1097/JES.0b013e3181e372ef

2.3 Linking Tensegrity to Sports Teams Collective Behaviors: Towards the Group-tensegrity Hypothesis

Caldeira, P., Fonseca, S. T., Paulo, A., Infante, J., & Araújo, D. (2020). Linking Tensegrity to Sports Team Collective Behaviors: Towards the Group-Tensegrity Hypothesis. *Sports Medicine - Open*. https://doi.org/10.1186/s40798-020-00253-y

2.3.1 Abstract:

Collective behavior in sports teams emerge from the coordination between players formed from their perception of shared affordances. Recent studies based on the theoretical framework of ecological dynamics reported new analytical tools to capture collective behavior variables that describe team synergies. Here, we introduce a novel hypothesis based on the principles of tensegrity to describe collective behavior. Tensegrity principles operate in the human body at different size scales, from molecular to organism levels, in structures connected physically (biotensegrity). Thus, we propose that a group of individuals connected by information can exhibit synergies based on the same principles (group-tensegrity), and we provide an empirical example based on the dynamics of a volleyball team sub-phase of defense.

Keywords: Synergies; Tensegrity; Team Sports; Perception-Action, Informational Coupling

2.3.2 Introduction

Performance analysis of sports teams has focused on the “what”, “who”, “where” and “when” of player behavior during competition. Notational data collection involves listing discrete actions performed in a given location on the field at specific times of the game, often relating these actions to a successful or unsuccessful outcome [1,2]. The analysis of such data can characterize precise moments and/or discern tendencies in the game. For example, in high-level volleyball, side-out and counter-attack performances are superior when the setter is in defensive zones [3], and first tempo attacks increase the probability of scoring in transition [4]. Although notational analyses provide important discrete information, it is also important to consider the “why” and “how” of observed behaviors and their circumstances and dynamics [5]. To observe this deeper layer of events, collective variables and specific tools are already available to capture team behavior dynamics resulting from the players’ cooperative interactions to achieve common goals [6]. Research using an ecological dynamics perspective on team collective behavior [7] has identified spatial-temporal features of movement patterns both intra- and inter-teams [8–10] that reveal properties of the ongoing synergies among players.

2.3.3 Sport Teams Collective Behaviors

From an ecological dynamics perspective, functional group synergies occur due to processes of self-organization and coordination between players that rely on their perception of shared affordances (i.e., common possibilities for action offered by the match) [5]. During team practice, players commonly perform tasks to learn how to adjust to each other’s actions by means of perceptual attunement [11] to match affordances (i.e., become sensitize to goal relevant sources of information). Thus, a synergy is a group action supported by match-specific information (i.e., specific circumstances) grounded in the properties of: i) *dimensional compression* - the reduction in degrees of freedom resulting from the self-organization of the system (i.e., the team). This self-organization increases the synchrony between team elements (i.e. phase relations, see [12,13] for details) and can be captured by collective or compound variables (e.g. cluster phase). The strength of such synchrony seems to be related to skill level and training volume [10,12,13]; ii) *reciprocal compensation* - individual actions to increase performance and compensate for other less effective individual contributions [14] are associated with a player’s capacity to adapt and synchronize to others’ movements [10,15]; iii) *interpersonal linkages for sharing work* - interpersonal linkages occur by aggregation, interdependence, among others (see [5,16] for a detailed discussion). The contribution of each individual to group behavior can be inferred from the area covered by the players and their distribution in the field [6], or from their movement trajectories over time [8,13]; iv) *degeneracy* - social networks and hypernetworks reveal the adaptability and flexibility of elements (players) as a part of a whole (team) for maintaining the desired performance. Such networks highlight the structure of organization within the team [17] and uncover the most common connection patterns [18–20], thereby identifying differences in team strategies [21,22].

Although the quantification of these synergistic properties with these methods elucidates synergetic behavior during competitive team sports, we hypothesized that an effective organization of sports teams may also be described as tensegrity systems. Specifically, a team corresponds to a large tensegrity system made of smaller tensegrity subsystems (players) connected by previously learned information and by information available in their performance environment. The conceptualization of sports teams as tensegrity systems can complement the information provided by the measurements of the properties described above, since it provides means to capture the initial conditions of a team as well as the influence of learned and trained processes in team positional configuration.

This novel approach may help coaches and sports professionals to understand how teams maintain their integrity (structural stability) despite constant individual changes (player actions and perceptions). Before introducing this hypothesis, we present a review of the literature on the dynamical properties of tensegrity structures [23,24] and their applications to mobile tensegrity architectures [25–27].

2.3.4 Tensegrity and Biotensegrity

The term “tensegrity” was first used in 1962 by the architect Buckminster Fuller to describe structures which maintain their integrity by global tension distribution (i.e., tension may be registered at the level of the structure as a whole unit) [28,29]. More recently, Motro (2003, in particular pp.19-23) proposed a broader definition of a tensegrity state: *“A tensegrity state is a stable self-equilibrated state of a system containing a discontinuous set of compressed components inside a continuum of tensioned component”* (p. 19). Other definitions of tensegrity and tensegrity systems can be found in the literature [24,28,30,31]. Tensegrity encapsulates the following set of properties: i) a pre-stress condition to reach equilibrium, which is a state of intrinsic tension allowing fast responses to changes in stress anywhere in the system; ii) energetic efficiency, as tensegrity system configurations favour efficiency and are capable of storing energy within the system itself; iii) nonlinear viscoelastic type properties such as non-linear stiffening, which allow tensegrity systems to become stronger when subjected to higher forces; and iv) omnidirectional stability is the ability to maintain functional properties independently of gravity direction [32,33]. Tensegrity structures occur in many areas, such as architecture [34], art [35], engineering [36], robotics [37], biological cell models [38], and human systems [39,40]. Tensegrity structures have high levels of functionality with energetic efficiency due to their synergetic geometry (i.e., the geometry that underlies the mechanics) [29]. Tensegrity structures in living organisms (biotensegrity) at multiple size scales is a complex phenomenon and has increasingly received attention from researchers [41]. However, these studies have focused on single organisms, as the tensegrity structures analysed have their components physically connected. In the present article, we explore the hypothesis that a group of individuals, such as a sports team, may also behave as a larger group-tensegrity system connected by information.

Tensegrity is a dynamic property comprising a tension network and a movement system [32]. The foundation of tensegrity structures is their geometry, and geodesic and triangular organizations. Straight lines connecting the centre of circles form hexagons and triangles, rendering a structure with higher strength and resilience [29]. Because geodesic geometry achieves the most efficient arrangement of space and materials, it is unsurprising that tensegrity structures are common in the natural world (e.g., viruses, proteins, carbon atoms, cells). Over the last decades, tensegrity architecture has been applied to biological organisms at multiple size scales, including molecular [42], cellular [43], tissue [44], organ [40] and organ system [39,45] levels. Examples are the self-stabilization properties of proteins and DNA [42], interactions between cells and the extracellular matrix controlling embryo patterning [38], muscle cells regulating muscle fibre size [46], lung fibre support system [40], the human spine [47], the muscular-ligament-skeletal system [48] and the haptic perception system [39].

Tensegrity as an explanation for the structural stability of complex biological systems

In biological organisms, self-assembly takes place as smaller units form larger stable structures with unique properties that were absent in the individual components, ultimately resulting in an organization of systems within systems [41]. Although the connectivity is maintained between systems, hierarchies are established, and multiple states emerge from ongoing synergies. Parts of a synergy are synergies themselves, and they are function-, task- and context-specific [49]. This process is congruent with the behavior of biological micro tensegrity structures and with macro-level interactions between tensegrity systems, as in those occurring during complex movements in humans. Tensegrity, as Turvey and Fonseca (2014) insightfully wrote, *"is a good biological model for Bernstein's level of synergies"* (p. 152). Bernstein's (1967,1996) work was fundamental to understand motor control, coordination, and the mechanisms whereby functional units combine to reduce the number of degrees of freedom for meeting task demands. To organize complex global movements, the muscular-ligament-skeletal system is *"supported by the basement level of tone"* [39, p. 143], which corresponds to the pre-stress property of tensegrity structures. The architecture at the level of tonus is a multi-fractal biotensegrity system exhibiting pre-stress at all levels, which allows system stability and fast adaptation to mechanical perturbations by re-distribution of tension. This pre-stress characteristic conveys the necessary support for self-organizing processes that enables synergies [39]. From an ecological dynamics perspective, synergies express relationships between their components, namely cooperation among components contextual roles to achieve a task goal (see [50], for a detailed discussion). Recently Cabe (2019) explored the hypothesis that in fact all (biological) perception engages in the tensegrity-based haptic medium. All movement adjustments involved in active perception affect the organismic tensegrity system [51]. Thus, tensegrity properties enable the synergies underlying complex human movement in task- and context-specific scenarios.

Biotensegrity is based on Perception-Action coupling

Biotensegrity is a functional concept, rather than an anatomical property [52], which implies perception-action coupling, or more generally, sensing-actuating links [36]. Perception-action coupling is situated at the level of the individual-environment system [53,54]. Perception and action regulate goal-directed actions in a given environment, which are adaptive behaviors. A performer is coupled to the environment through informational variables (optics, acoustics, and haptics), but also through the changes on the environment caused by their own actions [51, 52]. Tensegrity structures may be effectors of action (e.g., muscular-ligament-skeletal system) [55], a medium for haptic perception [39], or an organizational structure (e.g., lens of the eyes, [56]). Moreover, individuals are neurobiological degenerate systems, i.e., they can (structurally) vary motor behaviour to achieve the same function [57]. In all human action (even at rest) environmental influences (forces and information; in the ecological sense, information is ambient energy distributions, as it happens with light) are omnipresent. Perceiving as it happens in looking, listening, smelling, tasting, touching and, in fact, all exploration of stimulation arrays involves active movement and therefore have impact in the tensegrity structure (see [51] for a detailed discussion). Consequently, the tensegrity system is always in use, and the structure is continuously changing to adapt.

To date, research addressing the relationship between distinct tensegrity structures focused on an intrapersonal approach that assumes there is a physical connection between unit elements. However, in larger systems such as sports teams, the individual components (players) can also be connected by information [53]. The detected information constrains the individual's behavior in the same way as within-body mechanical forces constrain movement. Moreover, interpersonal movement coordination follows the same self-organizing dynamics [58] as bimanual coordination in an individual [59]. A similar phenomenon was found in individuals acting in coordination to perform a simple [60] or a complex task, such as a football match [13]. These examples highlight how information can connect components in a system similarly to mechanical linkages.

Tensegrity properties and sports teams

Contemplating the multifractality of tensegrity systems in individual human movement [39], we hypothesized that tensegrity properties can also be expressed in the collective behavior of a group of individuals with common goals (e.g., a sport team). Therefore, how can tensegrity systems properties can be related to sports team's collective behavior?

To address the property of pre-stress, which is a state of intrinsic tension allowing fast responses to changes in stress anywhere in the system, the question of "what constitutes the intrinsic tension of a sports team?" is of upmost importance. Intrinsic tension is created by the past experience, the team sport skill learning, the common path that characterizes a given team when they arrive to a performance context, the learned and practiced processes, including acting and perceiving affordances of others and for others [7]. Also, more permanent environmental constraints [61], such as rules or court dimensions influence intrinsic tension. All of these constraints confer information, omnipresent within the system formed by a sport team. Importantly, if when we consider a tensegrity in a physical structure, physical tension is means by which all the elements are linked, in this case it is informational tension that links the elements (players). However, how does a team maintain its intrinsic informational tension given the dynamic nature of the task? The players adjust their actions to the information available in every moment, which means that they change over time the structure they form, and thus they change team’s informational tension. The challenge is to keep the informational tension in a dynamic state that provides structure (team) stability and ensures responsiveness.

The property of energetic efficiency indicates that configurations that favour efficiency and are capable of storing energy within the system rely on the team's ability to express adaptive behavior. A sports team expressing adaptive behavior exhibits flexibility and variability to respond to events at any time. Flexibility to adapt facilitates the efficiency of the structure (the team) in response to the adversaries' actions, in particular, and game dynamic constraints, in general. A loss of efficiency in the structure can be linked to more uncoordinated actions such as unnecessary redundancies (e.g., players invading other players' areas of responsibility) or detrimental delays (e.g., players not positioning favorably to perform his or her share or to compensate teammates’ less successful actions). For example, experienced soccer players are more efficient (fewer positioning corrections) than less experienced players [62] and are more prompt to develop coordination tendencies in soccer tasks [63].

Tensegrity structures exhibit nonlinear viscoelastic type properties such as non-linear stiffening, which allows tensegrity systems to become stronger when subjected to higher forces. A sports team pressed by higher tension (e.g., expert adversaries, higher game intensity, etc.) needs to keep the structure stable to maintain adaptive behavior under such constraints. There is evidence that sports teams, which exhibit stability and efficiency in their coordinated actions, can overcome constraints that are theoretically inhibitory of success [64].

The property of omnidirectional stability, which is the ability to maintain functional properties independently of gravity direction, is related to sports teams in terms of space. Synchronization among players is not necessarily an indication of adaptive behavior. To be relevant, synchronization among players needs to harness local constraints, namely the space where it occurs [12]. Research on this topic address mainly longitudinal and lateral coordination [13,68,69]. However, different team sports have different specific constraint. For example, for volleyball, team structure can be defined in three dimensions, including height. Only by presenting the properties listed above, a sports team can exhibit the structural stability and adaptability of a tensegrity system. The question is: how can this be captured?

2.3.5 Geometrical Configurations and Architectural Control

Form-finding in a team: a quest for structural stability

Sports teams adopt positional or geometrical configurations in the field [5] to cope with the demands of the match and facilitate point-scoring while simultaneously preventing the opponent team from scoring [65]. Sports teams try to maintain structural stability to improve performance [66]. However, while geometrical configurations impose team constraints regarding the positions of players and their priority links, they also need to be adaptable to match dynamics (i.e., the evolving of match events) [9]. Research in interpersonal coordination has been conducted in different collective [67–69] and individual sports [70–72] and at different levels of social complexity (i.e., dyads, sub-groups, teams) [73]. It is clear from this body of research that the specific constraints of each sport, levels of social complexity, or sub-phases of the same sport (e.g., attacking, defending), are associated with different patterns of coordination. In sports teams, intra- and inter team co-adaptation and coordination tendencies vary among sports and within the same sport. Even when both teams of the same sport adopt similar positional distributions (e.g., 4:3:3 in soccer), they express different degrees of efficiency in their collective actions [74], indicating that the main feature of team performance is the dynamic capacity for maintaining responsive actions to local constraints. Geometrical configuration dependency between teams is eventually more evident in invasion sports were teams share the same space [22]. In net sports, since teams cannot recover the ball from the adversary space, the dependency of the positional configuration might be less dynamic, and previously trained plays may become more resistant to perturbation.

Given the behavior of mechanical tensegrity structures, which tend to maintain stability and integrity under external forces [75], stable geometrical configurations (i.e., adequate positional occupation to proficiently adapt to game dynamics) [76] similar to tensegrity structures emerge during a match. For example, the positions of volleyball players before initiating their actions to defend an opponent's attack for the following geometrical configuration (Figure 2.4):

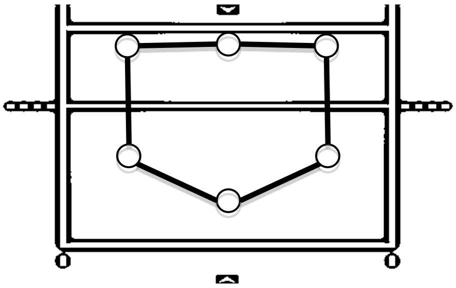


Figure 2. 4 Typical defensive geometrical distribution of players in a volleyball team. The figure represents half of the volleyball court, where the top is the net, and the bottom and right and left lines are the marked limits of the pitch. The six-round marks represent the players of the team defending this part of the pitch. The line parallel to the net is the three-meter line, which delimits the zone for the attackers

A typical defensive shape is maintained between matches and volleyball teams [77] because it offers an effective configuration for adapting efficiently and rapidly to the adversary's actions. Similarly, engineering tensegrity structures *"*[…] *provide the potential to control their shape and adapting to changing tasks and environments* […] *these systems exhibit geometrically nonlinear behavior and are strongly coupled* […]*"* [36, p. 1454-1455]. Determining a stable geometrical configuration in a tensegrity structure is referred as the *"form-finding"* problem, and it must consider: i) the patterns of connectivity that enable a stable state or tensegrity, and ii) the length parameters of rigid and tensile elements for a given stable connectivity pattern [78]. Form finding and structural stability also occur in team sports; for example, in football, skilled players tend to be distributed by design and become tactically balanced. Designs for space occupation that form a geometrical shape maintain the distances between elements within certain parameters and promote team performance [22,76,79]. Adaptive behaviors to maintain connections with teammates during a match are more robust in skilled players [22,80]. Several methods are currently available for form-finding, including non-linear programming, dynamic relaxation, and calculation of force density. These approaches calculate parameter values [81] and/or connectivity patterns (e.g., genetic algorithm) [78], and they can serve as an inspiration to team sports performance analysis. Thus, the hypothesis presented here offers a new avenue to explore the tensegrity properties or form-finding dynamics in team sports performance.

Control: architectural constrained solutions

In the human body, baseline levels of pre-stress, or preexisting tension, ensure a constant balance between internal and external forces. Postural states are associated with changes in internal forces, while external forces influence postural transitions [82]. Tensegrity structures adapt to the environment by changing intrinsic stress with sensors and actuators [37]. Considering a sports team as a group-tensegrity structure, the players' perception and action processes allow the tensegrity structure to emerge. While team actions can be highly plastic and dependent on immediate constraints (e.g., structure complexity of attack coverage in volleyball is dependent on attack tempo) [83], they may also benefit and usually rely on strategy or design based on player spatial distribution [84]. For example, it is common for players to have so-called "areas of responsibility" in defending or attacking sub-phases of the game [85].

In sports teams, geometrical configurations must allow fluid sharing of information between players who move freely but not separately from each other to search for efficient solutions. From the group-tensegrity hypothesis we are presenting, external constraints acting on the structure are mainly informational and omnipresent over time. Therefore, stability must be dynamic. In a weak tensegrity team's organization, its geometrical configuration, stable at one point in time, might lose stability as context unfolds. Only geometrical team's configurations capable of sustaining tensegrity-like properties will ensure adaptive dynamic stability. Several models for the dynamic control of tensegrity structures [36,86] offer insights for the analysis of sports team behavior. 'Deployment' is the process whereby a mechanical tensegrity structure in equilibrium changes to another state [87], such that a deployment path can be predicted within an equilibrium manifold. Can a deployment path favoring adaptive processes at different time scales be predicted for a sports team? Although equilibrium manifold and control variables can be calculated in tensegrity structures [87], this is not applicable (it is unrealistic to create a space state of all possible configurations) in sports teams. However, control variables such as length of *hard* and *soft* components may eventually be found in tensegrity structures connected by information, for example, in the coupling strength of players' shared actions and perceptions. Considering a group-tensegrity system connected by information, candidates to control variables would be available time to perceive (e.g., by changing ball or opponents speed); social density (e.g., by shifting the numerical ratio between teams), or ball proximity to target areas (e.g., changing the distance to the goal in soccer or to the net in volleyball). These variables will defy the system in its stability and responsive capability, eventually leading to differences in players' phase and distance relations. Importantly, Mcgarry et al. (2002) argue that sports teams may or may not exhibit high variability before the transition from a stable state to another [88].

Biotensegrity systems tend to be more complex than mechanical systems. However, at the cellular level, determining factors that produce ordered system-behavior have been identified [38]. Thus, models of larger tensegrity systems, such as sports teams, can be conceived.

2.3.6 Sports Team as a Group-tensegrity System: An exploration in Volleyball

A volleyball team in defensive tasks can be conceived as a group-tensegrity system (Figure 2) with essential pre-stress and energy efficiency properties eventually related to a controlled path towards an adaptive form-finding. As such, in a volleyball match, the players are connected informationally (e.g., via visual perception), and pre-stress as a pre-existing condition results from pre-defined strategies and learned shared-affordances. The most crucial pre-stress part of the performance is a result of learning from practice. Indeed, the players can practice to become perceptually attuned and calibrated to the shared affordances of others and for others in their team [7]. This process of learning shared-affordances is enhanced when practice offers environmental relevant properties mimicking the match situation and which are therefore representative of performance environments [73,89]. Behavior organization unfolds during the play and is supported by movement and on-line information detection [90] but constrained by the structure's pre-stress (Figure 2.5).

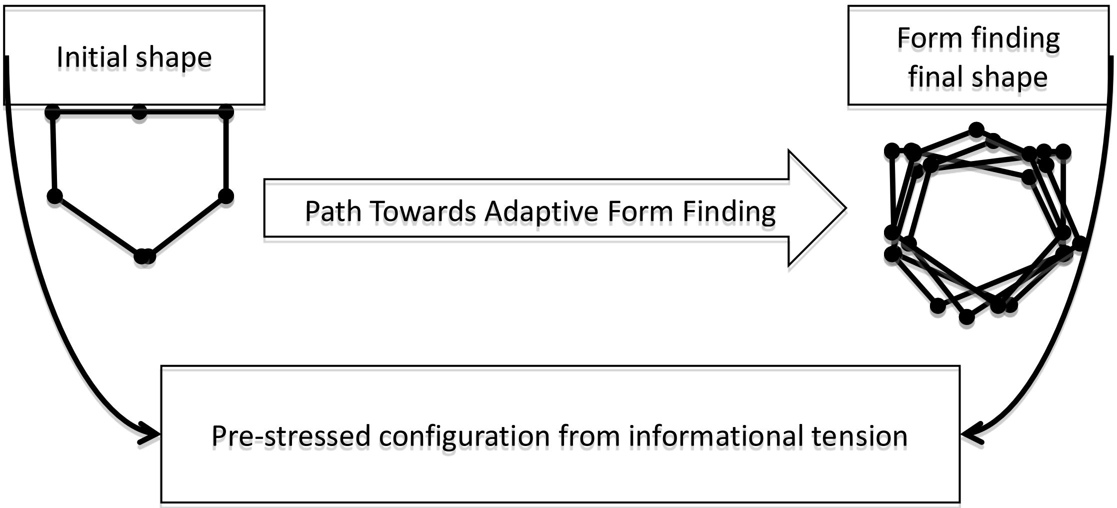


Figure 2. 5 Model of a sports team as a group-tensegrity system. Example of a volleyball team in defensive tasks, adaptive form-finding from pre-stressed configurations

While the opponent team develops their offensive play, a path to form-finding is initiated but hardly pre-determined, as athletes reorganize movements according to available informational constraints [91]. There is a close relationship between task control (i.e., adaptive behavior) and energy efficiency (i.e., intrinsic dynamics of each player), whereby higher expertise is linked to more efficient cooperation among players [62,63,92]. Energy efficiency in adaptive behavior should not be understood in absolute terms (less energy) but instead in the adequate movement variability/adjustment to meet task demands [93]. The control of system behaviors depends on functional variability (e.g., by exploring, selecting, or abandoning organizational states) [94–96] to manifest flexibility and self-organization [97]. Thus, we suggest that such properties enhance the possibilities of discovering stable geometrical configurations and, by extension, the chances of success in defensive play are increased (Figure 2.6).

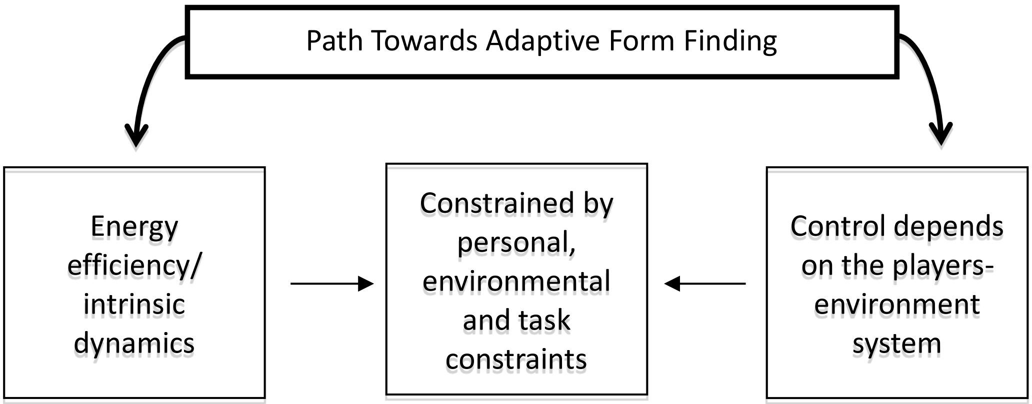


Figure 2. 6 Model of a sports team as a group-tensegrity system. Example of a volleyball team in defensive tasks, in which adaptive form-finding control and intrinsic dynamics are constrained by personal, environmental, and task constraints

An experimental test for investigating tensegrity principles in a volleyball team may be achieved by comparing a set of spatiotemporal (e.g., players phase and distance relations) variables between successful and unsuccessful defensive plays. Context-dependent collective behavior has been previously measured in sports teams [12,13], and such methods may be useful to capture pre-stress in the system (volleyball team in defensive tasks) during the path towards adaptive form-finding. Finally, movement variability dynamics [98,99] and the dynamics of space occupation can both contribute to determining how intrinsic dynamics and geometrical configurations evolve to adapt to ongoing constraints [79].

2.3.7 Conclusion

Research-based on ecological dynamics methods [5] has previously described synergic behavior in team sports. Here, we propose that a new approach based on the concept of tensegrity may raise new questions and accurately measure team sports dynamics and organization, thereby potentially offering valuable novel insights. In biological systems physically connected, tensegrity principles can be observed from a nanoscopic [42] to a macroscopic scale [39,48]. We propose that systems connected informationally as a group-tensegrity structure, such as sports teams, may follow a similar set of principles to achieve synergic adaptive behavior. Given that structure and function are highly complementary [100] we hold that group-tensegrity may inform in a structure to function direction (initial conditions and team geometrical configurations over time), whereas team synergies inform in a function to structure sense (dimensional compression, reciprocal compensation, interpersonal linkages and degeneracy), being, thus, complementary approaches within ecological dynamics.

The group-tensegrity hypothesis is a path that is opened to guide future (and needed) research. However, such research needs to consider the specific constraints of each sport, and the kinds of informational variables that challenge the properties of the system and the adjustments it reflects. By knowing these properties of team function and structure dynamics, training methods can be tested, and their efficacy monitored over preparatory cycles.

2.3.8 References

1. Eaves SJ. A history of sports notational analysis: A journey into the nineteenth century. Int J Perform Anal Sport. 2015;15:1160–76.

2. Hughes M, Franks IM. Notational Analysis of Sport: Systems for better coaching and performance in sport. second. Hughes M, Franks I, editors. Taylor & Francis; 2005.

3. Palao JM, Santos JA, Ureña A. Effect of setter's position on the spike in volleyball. J Hum Mov. 2005;48:25–40.

4. Costa GC, Caetano RCJ, Ferreira NN, Junqueira G, Afonso J, Plácido Costa R, et al. Determinants of attack tactics in youth male elite volleyball. Int J Perform Anal Sport. 2011;11:96–104.

5. Araújo D, Davids K. Team synergies in sport: Theory and measures. Front Psychol. 2016;7:1–13.

6. Araújo D, Silva P, Davids K. Capturing group tactical behaviors in expert team players. In: Baker D, Farrow D, editors. Routlegde Handb Sport Expert. New York: Routledge; 2015. p. 209–220.

7. Silva P, Garganta J, Araújo D, Davids K, Aguiar P. Shared knowledge or shared affordances? insights from an ecological dynamics approach to team coordination in sports. Sport Med. 2013;43:765–72.

8. Fonseca S, Milho J, Travassos B, Araújo D, Lopes A. Measuring spatial interaction behavior in team sports using superimposed Voronoi diagrams. Int J Perform Anal Sport. 2013;13:179–89.

9. Frencken W, de Poel H, Visscher C, Lemmink K. Variability of inter-team distances associated with match events in elite-standard soccer. J Sports Sci. 2012;30:1207–13.

10. Silva P, Chung D, Carvalho T, Cardoso T, Davids K, Araújo D, et al. Practice effects

on intra-team synergies in football teams. Hum Mov Sci [Internet]. Elsevier B.V.; 2016;46:39–51. Available from: http://dx.doi.org/10.1016/j.humov.2015.11.017

11. Davids K, Araújo D, Hristovski R, Passos P, Chow JY. Ecological dynamics and motor learning design in sport. Ski Acquis Sport Res Theory Pract. 2012;112–30.

12. López-Felip MA, Davis TJ, Frank TD, Dixon JA. A cluster phase analysis for collective behavior in team sports. Hum Mov Sci [Internet]. Elsevier; 2018;59:96–111. Available from: https://doi.org/10.1016/j.humov.2018.03.013

13. Duarte R, Araújo D, Correia V, Davids K, Marques P, Richardson MJ. Competing together: Assessing the dynamics of team-team and player-team synchrony in professional association football. Hum Mov Sci. 2013;32:555–66.

14. Latash ML. Synergy [Internet]. Synergy. New York: Oxford University Press, Inc.; 2008. Available from: http://www.scopus.com/inward/record.url?eid=2-s2.0-84921764332&partnerID=40&md5=a40db23d79d5ca23c152f2a6ff933895%5Cnhttp://www.oxfordscholarship.com/view/10.1093/acprof:oso/9780195333169.001.0001/acprof-9780195333169

15. Passos P, Milho J, Button C. Quantifying synergies in two-versus-one situations in team sports: An example from Rugby Union. Behav Res Methods. 2017;1–10.

16. Ingold T. The Life of Lines. London: Routledge; 2015.

17. Passos P, Davids K, Araújo D, Paz N, Minguéns J, Mendes J. Networks as a novel tool for studying team ball sports as complex social systems. J Sci Med Sport. 2011;14:170–6.

18. Gyarmati L, Kwak H, Rodriguez P. Searching for a Unique Style in Soccer. 2014;5–8. Available from: http://arxiv.org/abs/1409.0308

19. Laporta L, Afonso J, Mesquita I. Interaction network analysis of the six game complexes in high-level volleyball through the use of Eigenvector Centrality. PLoS One [Internet]. 2018;13:e0203348. Available from: http://dx.plos.org/10.1371/journal.pone.0203348

20. Ribeiro J, Davids K, Araújo D, Silva P, Ramos J, Lopes R, et al. The Role of Hypernetworks as a Multilevel Methodology for Modelling and Understanding Dynamics of Team Sports Performance. Sport Med. Springer International Publishing; 2019;49:1337–44.

21. Fewell JH, Armbruster D, Ingraham J, Petersen A, Waters JS. Basketball Teams as Strategic Networks. PLoS One [Internet]. 2012;7:e47445. Available from: http://dx.plos.org/10.1371/journal.pone.0047445

22. Esteves PT, Silva P, Vilar L, Travassos B, Duarte R, Arede J, et al. Space occupation near the basket shapes collective behaviours in youth basketball. J Sports Sci. 2016;34:1557–63.

23. Mirats Tur JM, Juan SH. Tensegrity frameworks: Dynamic analysis review and open problems. Mech Mach Theory. 2009;44:1–18.

24. Skelton RE, Helton WW, Chan W, Pinaud J-P, Adhikari R. An Introduction to Tensegrity Structures. Proc 40th IEEE Conf Decis Control [Internet]. 2001;1–6. Available from: http://ieeexplore.ieee.org/xpl/articleDetails.jsp?tp=&arnumber=980861&contentType=Conference+Publications&queryText=An+Introduction+to+Tensegrity+Structures

25. Masic M, Skelton RE. Open-loop control of class-2 tensegrity towers. Proc SPIE [Internet]. 2004;5383:298–308. Available from: http://link.aip.org/link/?PSI/5383/298/1&Agg=doi

26. Paul C, Roberts JW, Lipson H, Valero Cuevas FJ. Gait production in a tensegrity based robot. 2005 Int Conf Adv Robot ICAR ’05, Proc. 2005. p. 216–22.

27. Khazanov M, Humphreys B, Keat W, Rieffel J. Exploiting Dynamical Complexity in a Physical Tensegrity Robot to Achieve Locomotion. Adv Artif Life, ECAL [Internet]. 2013;12:965–72. Available from: http://mitpress.mit.edu/sites/default/files/titles/content/ecal13/978-0-262-31709-2-ch144.pdf

28. Fuller R. Tensile-integrity structures. US Patent; 1962.

29. Fuller RB, Ferkiss V, Applewhite EJ. Synergetics: Explorations in the Geometry of Thinking. Technol Cult [Internet]. 1976;17:104. Available from: http://www.jstor.org/stable/3103256?origin=crossref

30. Emmerich D. Constructions de reseaux autotendantes. 1963.

31. Pugh A. An introduction to tensegrity. University of California Press.; 1976.

32. Scarr G. Biotensegrity: The structural basis of life. Handspring Publishing; 2014.

33. Juan SH, Mirats Tur JM. Tensegrity frameworks: Static analysis review. Mech Mach Theory. 2008;43:859–81.

34. Liapi K, Kim J. A Parametric Approach to the Design of Vaulted Tensegrity Networks. Int J Archit Comput [Internet]. 2004;2:245–62. Available from: http://dx.doi.org/10.1260/1478077041518737%5Cnhttp://multi-science.metapress.com/content/w2v12k73486j1735/?genre=article&id=doi:10.1260/1478077041518737%5Cnhttp://www.metapress.com/content/w2v12k73486j1735/fulltext.p

df

35. Heartney E. Kenneth Snelson: forces made visible. Massachusets: Hard Press Editions; 2009.

36. Fest E, Shea K, Smith IFC. Active Tensegrity Structure. J Struct Eng. 2004;130:1454–65.

37. Paul C, Valero-Cuevas FJ, Lipson H. Design and control of tensegrity robots for locomotion. IEEE Trans Robot. 2006;22:944–57.

38. Ingber DE. Mechanical control of tissue morphogenesis during embryological development. Int J Dev Biol. 2006;50:255–66.

39. Turvey MT, Fonseca ST. The Medium of Haptic Perception: A Tensegrity Hypothesis. J Mot Behav [Internet]. 2014;46:143–87. Available from: http://www.tandfonline.com/doi/abs/10.1080/00222895.2013.798252

40. Weibel ER. What makes a good lung? Swiss Med Wkly [Internet]. 2009;139:375–86. Available from: http://europepmc.org/abstract/MED/19629765%5Cnhttp://dx.doi.org/smw-12270%5Cnhttp://www.ncbi.nlm.nih.gov/pubmed/19629765

41. Ingber DE. The architecture of life. Sci Am. 1998;278:48–57.

42. Liedl T, Högberg B, Tytell J, Ingber DE, Shih WM. Self-assembly of three-dimensional prestressed tensegrity structures from DNA. Nat Nanotechnol [Internet]. 2010;5:520–4. Available from: http://dx.doi.org/10.1038/nnano.2010.107

43. Ingber DE. Tensegrity II. How structural networks influence cellular information processing networks. J Cell Sci [Internet]. 2003;116:1397–408. Available from: http://jcs.biologists.org/cgi/doi/10.1242/jcs.00360

44. Huijing PA, Maas H. Adaptation of physiological cross-sectional area and serial number of sarcomeres after tendon transfer of rat muscle. Scand J Med Sci Sport. 2016;26:244–55.

45. Schleip R, Findley TW, Chaitow L, Huijing P. Fascia: The Tensional Network of the Human Body: The science and clinical applications in manual and movement therapy [Internet]. Elsevier; 2012. Available from: http://www.scopus.com/inward/record.url?eid=2-s2.0-84942891567&partnerID=40&md5=d40ae638dea7a5ac3e47ccaf378698cc

46. Huijing PA, Jaspers RT. Adaptation of muscle size and myofascial force transmission: A review and some new experimental results. Scand. J. Med. Sci. Sport. 2005. p. 349–80.

47. Levin S. The tensegrity-truss as a model for spine mechanics: biotensegrity. J Mech Med Biol. 2002;02:375–88.

48. Beach P. Muscles and meridians: The manipulation of shape. Elsevier Ltd.; 2010.

49. Kelso S. Synergies: Atoms of Brain and Behaviour. In: Dagmar S, editor. Prog Mot Control A Multidiscip Perspect. Springer; 2009. p. 83–91.

50. Profeta VLS, Turvey MT. Bernstein's levels of movement construction: A contemporary perspective. Hum Mov Sci [Internet]. Elsevier; 2018;57:111–33. Available from: https://doi.org/10.1016/j.humov.2017.11.013

51. Cabe PA. All Perception Engages the Tensegrity-Based Haptic Medium. Ecol. Psychol. 2019.

52. Turvey MT. Action and perception at the level of synergies. Hum Mov Sci. 2007;26:657–97.

53. Araújo D, Davids K, Hristovski R. The ecological dynamics of decision making in sport. Psychol Sport Exerc. 2006;7:653–76.

54. Warren WH. The dynamics of perception and action. Psychol Rev [Internet]. 2006;113:358–89. Available from: http://doi.apa.org/getdoi.cfm?doi=10.1037/0033-295X.113.2.358

55. Kugler PN, Scott Kelso JA, Turvey MT. On The Concept of Coordinative Structures as Dissipative Structures: I. Theoretical Lines of Convergence. Adv Psychol. 1980;1:3–47.

56. Yamada T, Richiert D, Tumminia SJ, Russell P. The tensegrity model applied to the lens: a hypothesis for the presence of the fiber cell ball and sockets. Med Hypotheses [Internet]. 2000;55:36–9. Available from: http://www.ncbi.nlm.nih.gov/pubmed/11021323

57. Seifert L, Komar J, Araújo D, Davids K. Neurobiological degeneracy: A key property for functional adaptations of perception and action to constraints. Neurosci Biobehav Rev [Internet]. Elsevier Ltd; 2016;69:159–65. Available from: http://dx.doi.org/10.1016/j.neubiorev.2016.08.006

58. Schmidt RC, Carello C, Turvey MT. Phase Transitions and Critical Fluctuations in the Visual Coordination of Rhythmic Movements Between People. J Exp Psychol Hum Percept Perform. 1990;16:227–47.

59. Kelso JAS. Phase Transitions and critical behavior in human bimanual coordination. Am J Physiol. 1984;246:1000–4.

60. Richardson MJ, Marsh KL, Baron RM. Judging and Actualizing Intrapersonal and

Interpersonal Affordances. J Exp Psychol Hum Percept Perform. 2007;33:845–59.

61. Newell K. Constraints on the development of coordination. In: Wade M, Whiting H, editors. Mot Dev Child Asp Coord Control. Dordrecht, Netherlands: Martinus Nijhoff; 1986. p. 341–60.

62. Gonçalves B, Marcelino R, Torres-Ronda L, Torrents C, Sampaio J. Effects of emphasising opposition and cooperation on collective movement behaviour during football small-sided games. J Sports Sci. 2016;

63. Folgado H, Gonçalves B, Sampaio J. Positional synchronization affects physical and physiological responses to preseason in professional football (soccer). Res Sports Med. 2018;

64. Vargas J, Loureiro M, Nikolaidis PT, Knechtle B, Laporta L, Marcelino R, et al. Rethinking Monolithic Pathways to Success and Talent Identification: The Case of the Women's Japanese Volleyball Team and Why Height is Not Everything. J Hum Kinet [Internet]. 2018;64:233–45. Available from: https://content.sciendo.com/view/journals/hukin/64/1/article-p233.xml

65. Gréhaigne JG, Richard JF, Griffin LL. Teaching and Learning Team Sports and Games. Teach Learn Team Sport Games [Internet]. 2004;1–188. Available from: http://www.scopus.com/inward/record.url?eid=2-s2.0-84911045733&partnerID=tZOtx3y1

66. Passos P, Araújo D, Davids K. Competitiveness and the process of co-adaptation in team sport performance. Front Psychol. 2016;7:1–5.

67. Ric A, Torrents C, Gonçalves B, Sampaio J, Hristovski R. Soft-assembled multilevel dynamics of tactical behaviors in soccer. Front Psychol. 2016;

68. Bourbousson J, Sève C, McGarry T. Space-time coordination dynamics in basketball: Part 1. intra- and inter-couplings among player dyads. J Sports Sci. 2010;

69. Passos P, Araújo D, Davids K, Gouveia L, Serpa S, Milho J, et al. Interpersonal pattern dynamics and adaptive behavior in multiagent neurobiological systems: conceptual model and data. J Mot Behav. 2009;41:445–59.

70. Pereira TJC, van Emmerik REA, Misuta MS, Barros RML, Moura FA. Interpersonal coordination analysis of tennis players from different levels during official matches. J Biomech. 2018;

71. Carvalho J, Araújo D, Travassos B, Esteves P, Pessanha L, Pereira F, et al. Dynamics of players' relative positioning during baseline rallies in tennis. J Sports Sci. 2013;

72. Krabben K, Orth D, van der Kamp J. Combat as an Interpersonal Synergy: An

Ecological Dynamics Approach to Combat Sports. Sport. Med. 2019.

73. Santos R, Duarte R, Davids K, Teoldo I. Interpersonal coordination in soccer: Interpreting literature to enhance the representativeness of task design, from dyads to teams. Front Psychol. 2018;9:1–6.

74. Vilar L, Araújo D, Davids K, Bar-Yam Y. Science of winning soccer: Emergent pattern-forming dynamics in association football. J Syst Sci Complex. 2013;

75. Averseng J, Dubé JF, Crosnier B, Motro R. Active control of a tensegrity plane grid. Proc 44th IEEE Conf Decis Control Eur Control Conf CDC-ECC '05. 2005;2005:6830–4.

76. Bourbousson J, Sève C, McGarry T. Space-time coordination dynamics in basketball: Part 2. The interaction between the two teams. J Sports Sci. 2010;28:349–58.

77. Schmidt B. Volleyball Steps to Sucess. Human Kinetics,Champaign, IL; 2016.

78. Paul C, Lipson H, Cuevas FJV. Evolutionary form-finding of tensegrity structures. Proc 2005 Conf Genet Evol Comput - GECCO '05 [Internet]. 2005;3. Available from: http://portal.acm.org/citation.cfm?doid=1068009.1068011

79. Silva P, Travassos B, Vilar L, Aguiar P, Davids K, Araújo D, et al. Numerical relations and skill level constrain co-adaptive behaviors of agents in sports teams. PLoS One. 2014;9:1–12.

80. Menuchi MRTP, Moro ARP, Ambrósio PE, Pariente CAB, Araújo D. Effects of spatiotemporal constraints and age on the interactions of soccer players when competing for ball possession. J Sport Sci Med. 2018;17:379–91.

81. Schek HJ. The force density method for form finding and computation of general networks. Comput Methods Appl Mech Eng. 1974;3:115–34.

82. Silva PL, Fonseca ST, Turvey MT. Is tensegrity the functional architecture of the equilibrium point hypothesis? Motor Control. 2010;14:1–6.

83. Laporta, L Nikolaidis , P, Thomas, L, Afonso J. Attack Coverage in High-Level Men's Volleyball: Organization on the Edge of Chaos? J Hum Kinet. 2015;47:249–57.

84. Duarte R, Araújo D, Correia V, Davids K. Sports Teams as Superorganisms. Sport Med [Internet]. 2012;42:633–42. Available from: http://link.springer.com/10.1007/BF03262285

85. Reynaud C. Coaching volleyball technical and tactical skills. Human Kinetics,Champaign, IL; 2011.

86. Sultan C, Corless M, Skelton RE. Symmetrical reconfiguration of tensegrity structures. Int J Solids Struct. 2002;39:2215–34.

87. Sultan C, Skelton R. Deployment of tensegrity structures. Int J Solids Struct. 2003;40:4637–57.

88. McGarry T, Anderson DI, Wallace S a, Hughes MD, Franks IM. Sport competition as a dynamical self-organizing system. J Sports Sci. 2002;20:771–81.

89. Dicks M, Davids K, Araújo D. Ecological psychology and task representativeness: Implications for the design of perceptual-motor training programmes in sport. In: Hong Y, Bartlett R, editors. Routledge Handb Biomech Hum Mov Sci. London: Routledge.; 2008. p. 129–39.

90. Hristovski R, Davids K, Araújo D, Passos P. Constraints-induced Emergence of Functional Novelty in Complex Neurobiological Systems : A Basis for Creativity in Sport. Psychol Life Sci. 2011;15:175–206.

91. Pinder RA, Davids K, Renshaw I, Araújo D. Manipulating informational constraints shapes movement reorganization in interceptive actions. Attention, Perception, Psychophys. 2011;73:1242–54.

92. Seifert L, Button C, Davids K. Key properties of expert movement systems in sport: An ecological dynamics perspective. Sport. Med. 2013. p. 167–78.

93. Cardis M, Casadio M, Raganathan R. High variability impairs motor learning regardless of whether it affects task performance. J Neurophysiol [Internet]. 2017;jn.00158.2017. Available from: http://jn.physiology.org/lookup/doi/10.1152/jn.00158.2017

94. Davids K, Bartlett R, Glazier P, Araújo D. Movement Systems as Dynamical Systems. 2003;33:245–60.

95. Turvey MT. Coordination. Am Psychol. 1990;

96. Newell KM, Corcos DM. Issues in variability and motor control. In: Newell K, Corcos DM, editors. Var Mot Control. Human Kinetics,Champaign, IL; 1993. p. 1–12.

97. Schöner G, Kelso J a. S. A dynamic pattern theory of behavioral change. J Theor Biol. 1988;135:501–24.

98. Orth D, van der Kamp GJP, Memmert D, Savelsbergh GJP. Creative motor actions as emerging from movement variability. Front Psychol. 2017;8:1–8.

99. Seifert L, Komar J, Barbosa T, Toussaint H, Millet G, Davids K. Coordination Pattern Variability Provides Functional Adaptations to Constraints in Swimming Performance. Sport Med. 2014;1333–45.

100. Kelso JA, Engstrom DA. The Complementary Nature. Massachusets Institute of Technology; 2006

3 Constraints-led approach and synergetic behavior in volleyball: Experimental studies

3.1 Accommodating individual differences in a team: the practice of the volleyball spike.

Caldeira, P., Infante, J. & Araújo, D. (under submission) Accommodating individual differences in a team: the practice of the volleyball spike.

3.1.1 Abstract:

Manipulating task constraints according to individual differences is a hallmark of the Constraints-led Approach. However, in team sports, it is not clear how to design practice sessions addressing individual differences and simultaneously focusing in team goal achievement. The aim of the study was to test how manipulation of court dimensions according to players' spike performance, could enhance volleyball spike accuracy, as well the movement timing of the horizontal approach phases to the spike jump.

Twelve under 17 female volleyball players (mean height = 172.25±8.41 cm; mean age=15.66±0.88 years; practice experience =3.58±0.79 years) were randomly assigned to the group where individual differences (IGC) were addressed or the group which focused on group goals (GGC), balanced according to an individual spike accuracy pre-test. The intervention consisted of the practice of volleyball spikes (60 trials for each player) followed by post and follow-up spike accuracy tests. The duration of the horizontal approach phases to the spike was measured and compared within groups across tests.

Results showed that players training in IGC significantly improved spike accuracy from pre to post-test and maintain the improvement in the follow-up test and in the GCG there was no improvement. For the take-off duration of the horizontal approach, the IGC showed no differences across tests, while the GGC showed an increase among the pre-test and both the post and the follow-up tests.

A constraints-led approach guided task manipulation for considering individual differences resulted in improved performance in spike accuracy, contributing to team goal achievement. The process for such for improving performance was based on the stabilization of the time duration of horizontal approach phase of the take-off but with a high variability.

Keywords: Constraints-led approach, individual differences, coordinative structures, volleyball

3.1.2 Introduction

Developing team dynamics and performance while addressing individual differences is a highly demanding task for coaches and practitioners. Traditionally, practice design for team sports considers the whole or group of players that share the same roles (e.g., defenders or attackers) and consequently training tasks tend not to be adjusted to the specific characteristics of the individuals. However, the ecological dynamics approach argues for the need to consider individual constraints, as well as the unique reciprocal relation between the individual and the environment (Davids, Araújo, Hristovski, Passos, & Chow, 2012; Davids, Araújo, & Seifert, 2014; Davids, Araújo, Vilar, Renshaw, & Pinder, 2013). The constraints-led approach (CLA) (Davids et al., 2003), grounded on ecological dynamics theoretical framework (Araújo et al., 2020), supports practitioners in practice design trough the manipulation of relevant constraints from the three broad categories of task, individual and environmental constraints. The interaction of constraints from these categories (Newell, 1986) leads to emergent behaviour, based on the guided self-organization. CLA relies on several principles such as the mutuality of performer and environment, the perception and action coupling (Gibson, 1979), the self-organization of behaviour under constraints (Araújo et al., 2006), adaptative variability (Davids, Button, Araujo, Renshaw, & Hristovski, 2006) and of particular interest to the aim of this study the accommodation of individual constraints (Button et al, 2020 for a review).

3.1.3 Constraints- Led Approach: accommodating individual differences in a team

Individual differences are commonly accepted has an important constraint in practice organization, but it is often limited to recognizing that all athletes are different and specific variations of training protocols should be considered (Brewer, 2017; Zatsiorsky & Kraemer, 2006). Within CLA, individualization reflects the relationship of the athlete’s intrinsic dynamics (i.e., dispositional tendencies) and the specific affordances of the sport (Renshaw et al., 2019). The athletes’ set of anthropometric, physiological, cognitive and emotional constraints shape their search for solutions for achieving task goals in a given performance environment. This perspective is in contrast with a practice designed to achieve an ideal movement by athletes and moves towards a careful manipulation of task constraints according to individual constraints, facilitating unique movement solutions that achieve task goals. In implementing CLA, equipment manipulation is a common strategy as recently experimented in field hockey by Brocken et.al. (2020). In a cross-over design intervention, young field hockey players ranging from

0 to 4 years of experience practiced either with a regular or a modified more unpredictable ball. Results show that independently of age or skill level, training with a modified ball led to improved performance. The authors concluded that increased movement variability was beneficial for improving performance (Brocken et al., 2020). In team sports, manipulating the number of players in each group have been tested to influence team behaviors (Travassos, Vilar, Araújo, & McGarry, 2014), creating more action opportunities (Vilar et al., 2014) or changing exploratory behaviors according to the number of opponents (Ric et al., 2016). Moreover, by manipulating pitch dimensions, Casamichana and Castellano (2010) showed differences in soccer drills, related to physical, physiological, perceived exertion and motor responses while keeping the number of players constant. Also, manipulating court dimensions, rules and scoring format promoted functional performance behaviours by young tennis players (Fitzpatrick et al., 2018). Frencken et al. (2013) demonstrated that in a soccer experimental study, the manipulation of pitch size by either favouring length (24x20m), width (30x16m) or a combination of both (24x16m) change team adaptive behaviours. However, Clark et.al. (2019) in a systematic review of the CLA highlight for the need to account for participants' skill, lack of control group or failing to have follow-up tests. (Clark et al., 2019). In the present study we addressed some of these concerns by manipulating the practice areas according to individual skill differences (vs. no manipulation) and tested how this manipulation impacted on players spike accuracy (pre-post-test and follow-up). Volleyball spiking performance can be influenced by jump capacity (Fuchs et al., 2019) and jump capacity by strength and considering that the participants were young female players, maturity offset was calculated according to Koziel and Malina (2018). Several studies investigated the horizontal approach in volleyball spike from a kinematic perspective (Fuchs et al., 2019; Wagner et al., 2009) or quantitative contribution to spike jump (Ikeda et al., 2018). In the present study, assuming that kinematics will be highly dependent on individual differences, the focus was on the duration of each phase and how might be re-organized from pre to post intervention. Additionally, since the duration of horizontal displacement is determinant to spike performance (Fuchs et al., 2019) we tested if the experimental condition changed the duration of each phase of the horizontal approach.

3.1.4 Methods

Sample

Twelve under 17 years old Portuguese national league volleyball players (practice experience at the national level =3.58±0.79 years) participated in the study (table 3.1). These players were involved in the national championship and at the time of the intervention were in the top six teams competing for the national title. The study was approved by the Ethics Council of the Faculty of Human Kinetics, University of Lisbon. The first session was a pre-test to assess the spike accuracy performance (described below). Based on pre-test results the higher and lower six accurate players were identified. To balance the groups, three players from the top six and three players from the lower six scorers were randomly assigned to each of the two groups. The experimental group was the one where individual performance was considered (individuality in group condition - IGC). The control group considered overall group task goals (general group condition - GGC) (Figure 3.1a).

Table 3. 1 Participant's data for age, height and maturity offset.

	IGC	GGC	*t*	*p*
Age (years)	15.8 ± 0.75	15.5 ± 1.29	0.522	0.61
Height (cm)	173.3 ± 9.52	171.5 ± 6.55	0.333	0.74
Maturity Offset (years)	3.87 ± 0.64	3.53 ± 1.26	0.561	0.59

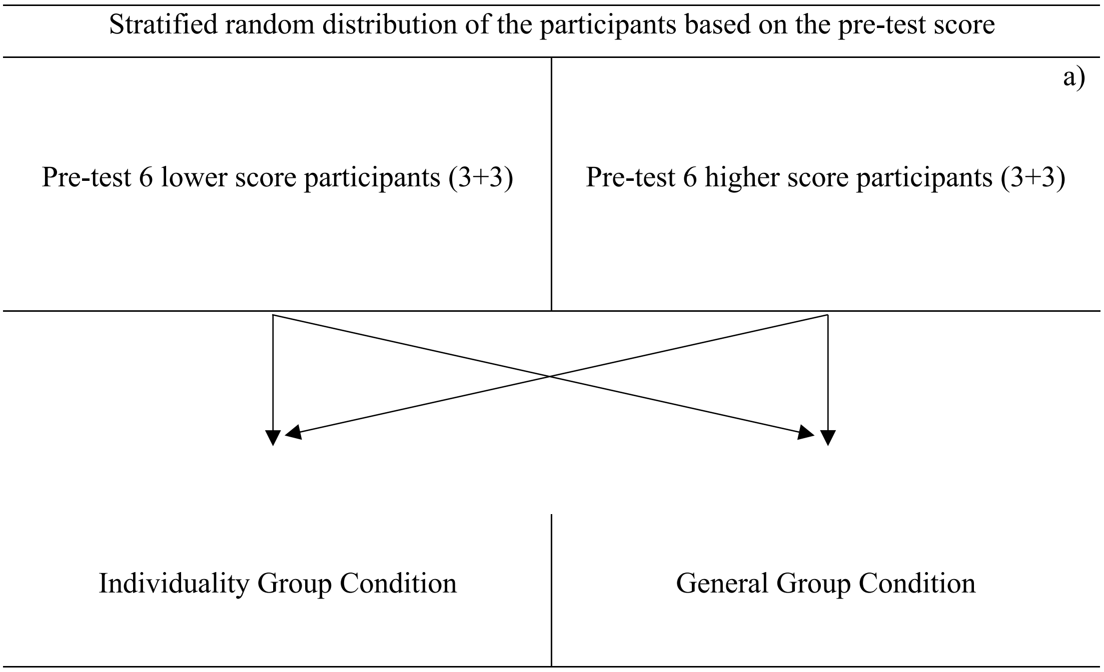
No significant differences between groups

IG - individuality in group condition

GGC - general group condition

Intervention

Two tasks were designed for spike training where manipulations of the court dimensions were implemented (figure 3.1b). A task (task 1) had bigger dimensions to perform combined with a smaller target and another task (task 2) had a smaller area to perform (less ball flight time thus easy to intercept) was combined with a bigger target area to direct the spike. Task 1 is scaled to the pre-test higher scorers and task 2 to the pre-test lower scorers. The IGC had three players (pre-test higher scorers) practicing in task 1 and three players (pre-test lower scorers) practicing in task 2, therefore, in tasks scaled to individual differences. The GGC players practiced in the inverse conditions, pre-test higher scorers practicing in task 2 and pre-test lower scorers practicing in task 1.



b)

Task Manipulation

1) Designed for higher scorers		2) Designed for lower scorers	
Area to Execute	Target area	Area to Execute	Target area
4.5x3m	2.25X9m	2.25mX3m	4.25x9m

Figure 3. 1 Study design and task manipulation

a) Distribution of participants to IG or GG conditions based on pre-test score.

b) Manipulation of the area to execute the spike and target area, according to pre-test scores, for the IGC.

The intervention for both groups/conditions started with a general warm-up followed by a 2x2 ball drill to prepare the players for the spiking task. Each player performed 60 repetitions in the assigned group, with the players attacking one at the time and recovering the ball after. The instruction to recover the ball before a new spike intended to allow recovering between trials.

Testing Procedures

Following previous studies, spiking accuracy was tested using targets on the floor of the opposite half-court (Figure 3.2) (Chow et al., 2008; Lee et al., 2014). The test was conducted using official court dimensions with the players attacking in zone 4 to targets that were placed in the diagonal and down the line of the attack zone. The targets' location corresponds to the court areas less likely to be covered by the opponents block in a game scenario (Reynaud, 2011)

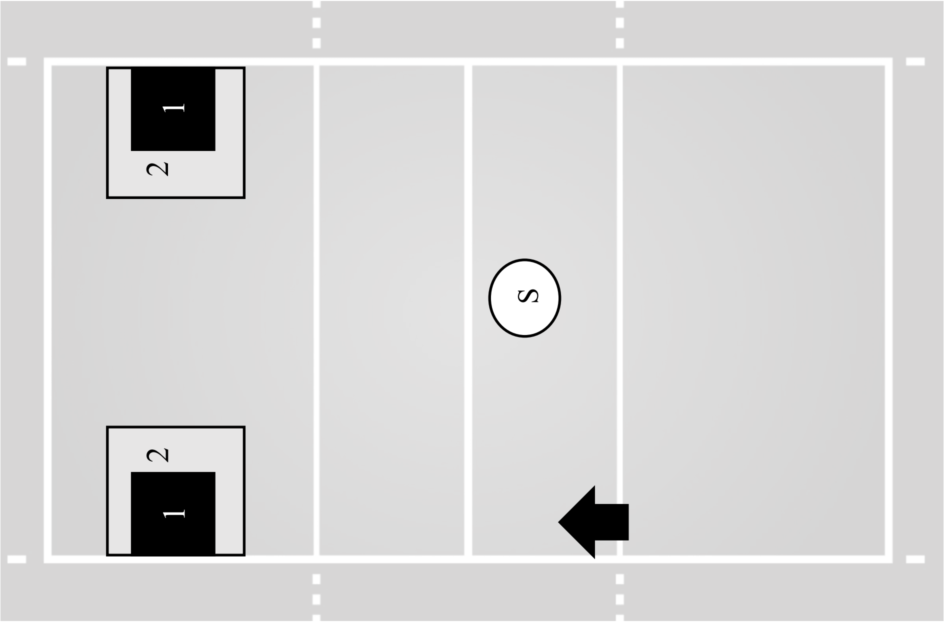


Figure 3. 2 Volleyball court indicating the procedures for the spike accuracy test set-up.

Black arrow - spike

S - setter

Targets 1=3points; targets 2 = 1 point

Spikes hitting the centre area of the target scored 3 points, hitting the adjacent area 1 point and hitting anywhere else 0 points. Pre, post and follow-up tests followed the same procedures with players performing 12 non-consecutive trials to avoid fatigue. To guaranty consistency in the sets for spiking, all sets in all tests were made by an expert international level female setter with 22 years of volleyball experience as a setter. After the pre-test, participants trained the spike according to the group/condition which they were assigned. Five days after the intervention, a post test was conducted and six days after this a follow-up test was performed.

Variables and analysis

Spike accuracy. Spike accuracy was tested 3 times: before the intervention (pre-test), after the intervention (post-test) and in a follow-up test. Using video observation, each player's trial was scored according to the test classifications (0, 1 or 3 points) for accuracy. The test consisted in each player performing 12 trials. The score for each player ranged between 0 and 36 points. Two players were excluded from the study due to injury or illness. A total of 120 repetitions were available for analysis (*N=72* for IGC and *N=48* for GGC). Repeated measures ANOVA was used to compare spike accuracy measures within and between groups. T-tests were used to compare the set flight time between groups in each test performed. Significance level of 0.05 was set for all statistical tests.

Horizontal approach phases duration. The horizontal approach is determinant in volleyball spiking performance and can be divided in the phases of "orientation step", "planting step" and "take-off" (Fuchs et al., 2019). Orientation step is the first step in the volleyball spike horizontal approach and, as the name reveals, is the main responsible for the trajectory the player will take until the jump to intercept the ball (Toyoda, 2011). Orientation step duration was defined as the time duration (ms) between the moment the foot leaves the ground to the moment the same foot touches the ground. The planting step in the horizontal approach provides deceleration and it is crucial for efficiency in converting horizontal to vertical velocity (Fuchs et al., 2019; Ikeda et al., 2018). Planting step was defined as the time duration (ms) from the end of the orientation step to the contact to the floor of both feet in the planting step. Take-off is the last phase of the horizontal approach and vertical velocity at this moment is correlated with jump height (Ikeda et al., 2018). Take-off duration was defined as the time duration (ms) between the end of planting step (contact o both feet in the ground) to the moment both feet leave the ground initiating the vertical jump.

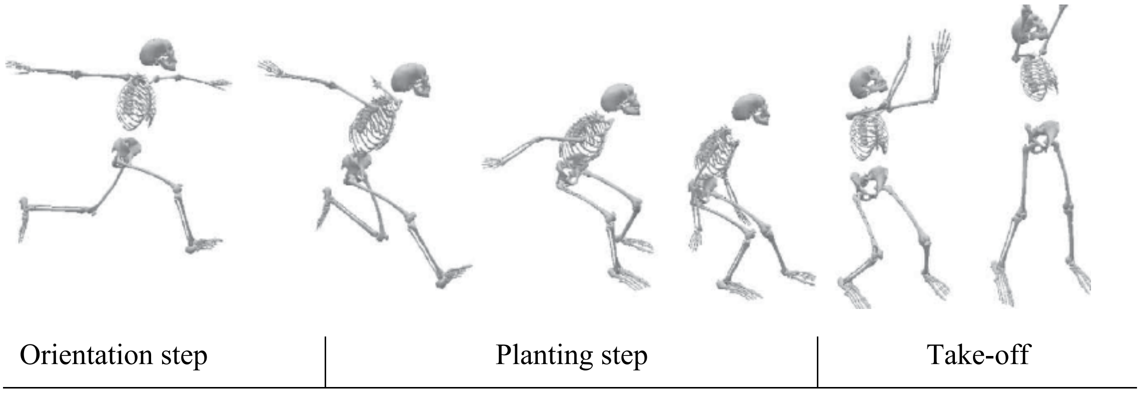


Figure 3. 3 Adapted from (Wagner et.al., 2009). Phases of the horizontal approach to volleyball spike.

The 3 phases are performed sequentially (figure 3.3) before the player jumps to spike the ball. To compare within groups the duration of each phase of the horizontal approach a repeated measures ANOVA was used. Additionally, standard deviations were analysed, and coefficient of variation (CV=100 x standard deviations/mean) was calculated. Coefficient of variation expresses sample variability relative to mean of the sample (Amende et al., 2005; Goto & Mascie-Taylor, 2007). The significance level was set a priori $p \leq 0.05$.

3.1.5 Results

Spike accuracy

Figure 3.4 depicts spike accuracy scores for both groups in pre, post and follow-up tests. The IGC showed significant differences (*F (3,70) =4.609, p=0.05*) in mean accuracy scores from pre-test to both post and follow-up tests. The GGC showed no significant differences (*F (3,46) =0.135, p=0.87*) from pre-test to post and follow-up tests. Results between groups showed no significant differences for spike accuracy (*F (1,118) =0.400, p=0.52*) and set flight time at pre-test (t *(118) = 1.045, p = 0.29*), post-test (t *(118) = -1.578, p = 0.11*) and follow-up test (t *(118) = -1.747, p = 0.08*).

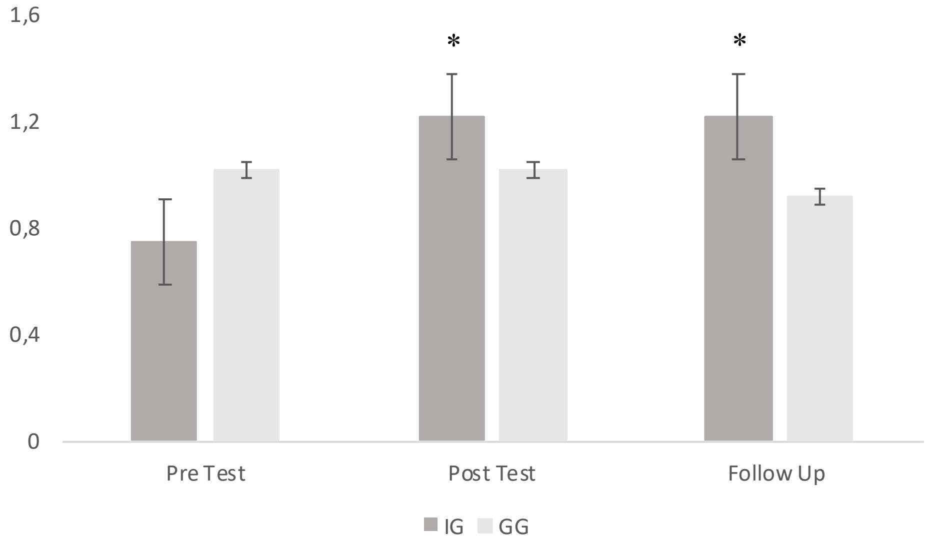


Figure 3. 4 Comparison of the spike accuracy (means and standard deviation) between IGC and GGC, in the three tested moments.

IG - Individuality Group Condition, GG - General Group Condition

* Significant differences in IG between pre and post-test and pre and follow-up test, *p*≤0.05

Horizontal approach phases duration

Results of phase duration and coefficient of variation from both groups are presented in figure 3.5a and 3.5b respectively. Orientation step time was significantly different for the IGC (*F (3,70) = 15.678, p=0.05*) and the GGC (*F (3,46) = 16.091, p=0.05*) from pre to post-test and from pre to follow-up test. Planting step time was significantly different from pre-test and post-test in IGC (*F (3,70) = 2.998 p=0.05*) and in GGC (*F (3,46) = 6.474, p=0.05*). Take-off time was significantly different from pre-test to both post and follow-up in GGC (*F (3,46) = 14.595, p=0.05*). The IGC showed no significant differences (*F (3,70) = 1.988, p=0.145*) in take-off time between pre-test and posterior tests.

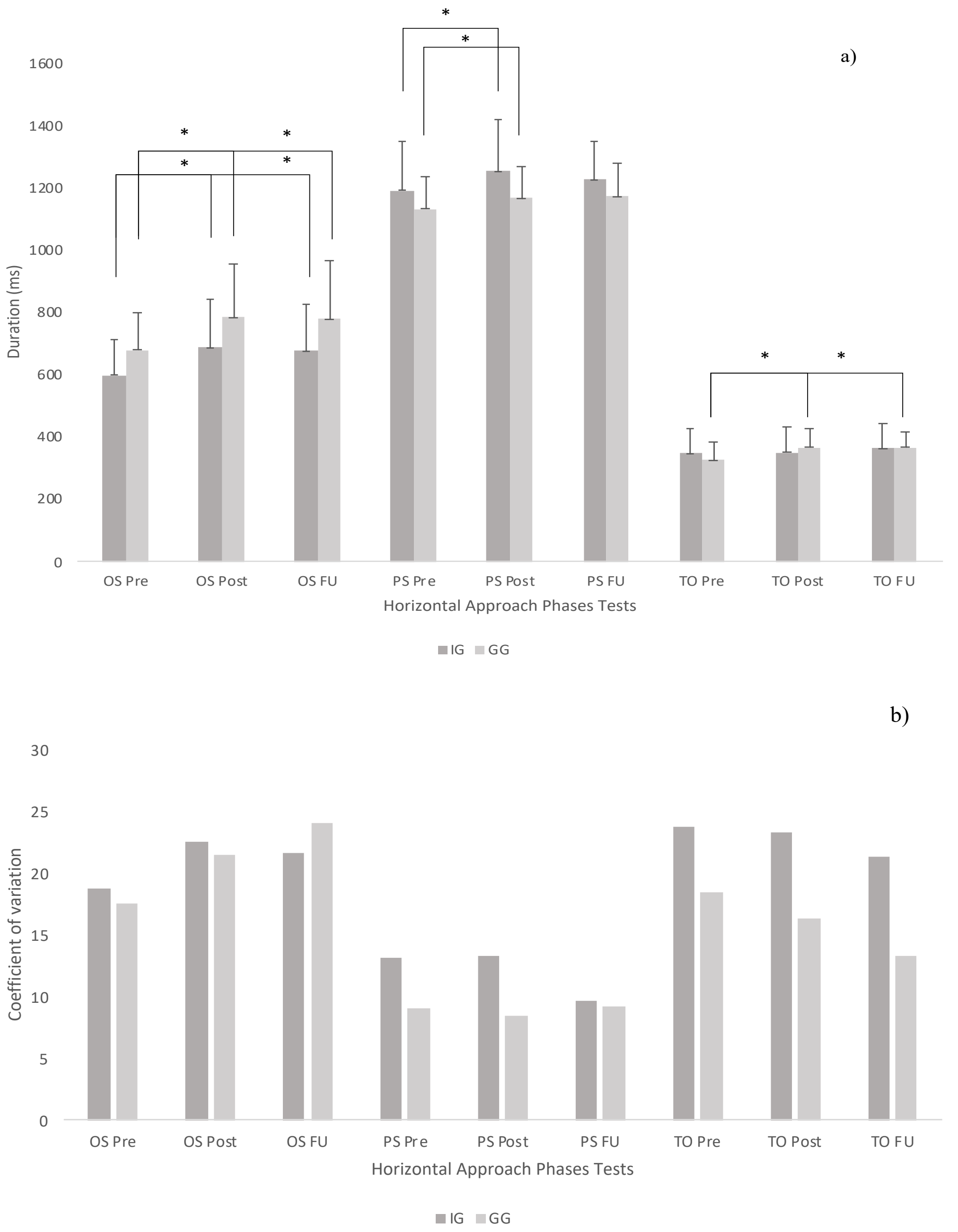


Figure 3. 5 Figure 5 Horizontal approach phases duration.

a) Duration (ms) of orientation step, planting step and take-off in pre, post and follow-up tests of IG and GG

b) Coefficient of variation of orientation step, planting step and take-off in pre, post and follow-up tests of IG and GG

IG - Individuality Group Condition, GG - General Group Condition, OS Pre – Orientation Step Pre-test, OS Post - Orientation Step Post-test, OS FU - Orientation Step Follow up test, PS Pre – Planting Step Pre-test, PS Post - Planting Step Post-test, PS FU - Planting Step Follow up test, TO Pre – Take-off Pre-test, TO Post - Take-off Post-test, TO FU - Take-off Follow up test

* Significant difference between pre and post-test and pre and follow-up test, *p*≤0.05

3.1.6 Discussion

The main aim of the study was to test the effects of task manipulation based on individual differences, in volleyball spike accuracy. The players who practiced according to their individual differences showed significant improvement in spike accuracy in post and follow-up tests. These results are supported by the literature. For example, Timmerman et.al. (2015) scaled court dimensions and net height according to the temporal demands of the children matches in comparison with the adult matches, in tennis, finding positive effects in children match performance. In the present study, the task manipulation adjusting the space and the targets to the individual differences, are related to different temporal demands in the volleyball spike. Adjusting the court dimensions to match individual differences allowed for a practice suited for players' capacities, more demanding and complex for initial higher scorers and less demanding and simple for lower scorers. Simplification instead of decomposing tasks is a fundamental feature of CLA (Davids et al., 2003). The adequate task simplification can tap into the individual intrinsic dynamics promoting skill learning and performance (Davids et al., 2012). The spike accuracy findings indicate that it might be desirable within a volleyball team to adjust task constraints according to the players current level of performance.

In the horizontal approach to the spike jump, the two groups presented different organizations for the time duration of each of the three phases. Both groups changed significantly the duration of the orientation and planting steps from pre to post-test. In the take-off, only GGC continued to show differences across the three tested moments. Chow et.al. (2008) showed that the reduction of degrees of freedom (dof) in a component of a coordinative structure to improve accuracy in a sport task, occurs as a consequence of practice. How much and which dof are reduced within a coordinative structure tends to be highly individualized (Chow et al., 2008) but also dependent of tasks constraints (Newell & Vaillancourt, 2001). Results from the present study suggest that IGC stabilized the duration of the take-off and explored the time spent in previous phases as an adaptive strategy. Accordingly, it seems that to improve the specific task of spiking with accuracy it is important to reduce dof of the horizontal approach in the phase closest to the ball contact. However, although the players from the IGC stabilized the take-off time duration showing no differences across the evaluation moments, it is the phase which presents higher variability (coefficient of variability). This contrasts with findings of temporal organization of movement in baseball where a progressive reduction of variability up to ball contact was found (Katsumata, 2007). However, contrasting with baseball, in the volleyball spike, after the horizontal approach and before contacting the ball, there a is subsequent phase (the flight). Possibly the strategy of reducing dof in the take-off, found in the present study, is to conserve a certain degree of flexibility (expressed by higher variability) to meet the specific task demands of volleyball spiking.

Having only one training session was a limitation in the present study that we tried to minimize by not having any regular training between the intervention and the post-test. Future studies may include more sessions. Moreover, movement re-organization channelled by task manipulation as an explanatory process to understand skill learning should be pursued in future studies in detailed.

3.1.7 Conclusion

In conclusion, players who practiced according to their individual differences improved spike accuracy and tended to stabilize the time duration of take-off phase as a strategy to reduce degrees of freedom in the coordinative structure for spiking. Interestingly, the time duration of the take-off phase, presented higher variability as a form of flexibility or degenerancy (Seifert el al., 2016) to meet task demands.

3.1.8 References:

Amende, I., Kale, A., McCue, S., Glazier, S., Morgan, J. P., & Hampton, T. G. (2005). Gait dynamics in mouse models of Parkinson’s disease and Huntington’s disease. *Journal of NeuroEngineering and Rehabilitation*. https://doi.org/10.1186/1743-0003-2-20

Araújo, D., Davids, K., & Hristovski, R. (2006). The ecological dynamics of decision making in sport. *Psychology of Sport and Exercise*, *7*(6), 653–676. https://doi.org/10.1016/j.psychsport.2006.07.002

Araújo, D., Davids, K., & Renshaw, I. (2020). Cognition, Emotion and Action in Sport. In *Handbook of Sport Psychology*. https://doi.org/10.1002/9781119568124.ch25

Brewer, C. (2017). *Athletic Movement Skills Training for Sports Performance*. Human Kinetics,Champaign, IL.

Brocken, J. E. A., van der Kamp, J., Lenoir, M., & Savelsbergh, G. J. P. (2020). Equipment modification can enhance skill learning in young field hockey players. *International Journal of Sports Science and Coaching*. https://doi.org/10.1177/1747954120918964

Chow, J. Y., Davids, K., Button, C., & Koh, M. (2008). Coordination changes in a discrete multi-articular action as a function of practice. *Acta Psychologica*, *127*(1), 163–176. https://doi.org/10.1016/j.actpsy.2007.04.002

Clark, M. E., McEwan, K., & Christie, C. J. (2019). The effectiveness of constraints-led training on skill development in interceptive sports: A systematic review. *International Journal of Sports Science and Coaching*, *14*(2), 229–240. https://doi.org/10.1177/1747954118812461

Davids, K, Button, C., Araujo, D., Renshaw, I., & Hristovski, R. (2006). Movement models from sports provide representative task constraints for studying adaptive behavior in human movement systems. *Adaptative Behaviour*, *14*(1), 73–95. https://doi.org/10.1177/105971230601400103

Davids, Keith, Araújo, D., Hristovski, R., Passos, P., & Chow, J. Y. (2012). Ecological dynamics and motor learning design in sport. *Skill Acquisition in Sport: Research, Theory and Practice*, *March*, 416. https://doi.org/10.13140/RG.2.1.2297.0089

Davids, Keith, Araújo, D., & Seifert, L. (2014). EXPERT PERFORMANCE An ecological dynamics perspective. *Routledge Handbook of Sport Expertise*, 130–144.

Davids, Keith, Araújo, D., Shuttleworth, R., & Button, C. (2003). Acquiring Skill in Sport: A Constraints-Led Perspective. *International Journal of Computer Science in Sport*, *2*, 31–39.

Davids, Keith, Araújo, D., Vilar, L., Renshaw, I., & Pinder, R. (2013). An ecological dynamics approach to skill acquisition: Implications for development of talent in sport. *Talent Development and Excellence*, *5*(1), 21–34.

Fitzpatrick, A., Davids, K., & Stone, J. A. (2018). Effects of scaling task constraints on emergent behaviours in children's racquet sports performance. *Human Movement Science*. https://doi.org/10.1016/j.humov.2018.01.007

Fuchs, P. X., Fusco, A., Bell, J. W., Duvillard, S. P. Von, Cortis, C., & Wagner, H. (2019). Movement characteristics of volleyball spike jump performance infemales. *Journal of Science and Medicine in Sport*, *2018*, 1–5. https://doi.org/10.1016/j.jsams.2019.01.002

Gibson, J. J. (1979). The Ecological Approach to Visual Perception. In *Houghton Mifflin-Boston*.

Goto, R., & Mascie-Taylor, C. G. N. (2007). Precision of measurement as a component of human variation. *Journal of Physiological Anthropology*, *26*(2), 253–256. https://doi.org/10.2114/jpa2.26.253

Ikeda, Y., Sasaki, Y., & Hamano, R. (2018). Factors influencing spike jump height in female college volleyball players. *Journal of Strength and Conditioning Research*. https://doi.org/10.1519/JSC.0000000000002191

Katsumata, H. (2007). A functional modulation for timing a movement: A coordinative structure in baseball hitting. *Human Movement Science*, *26*(1), 27–47. https://doi.org/10.1016/j.humov.2006.09.005

Lee, M. C. Y., Chow, J. Y., Komar, J., Tan, C. W. K., & Button, C. (2014). Nonlinear pedagogy: An effective approach to cater for individual differences in learning a sports skill. *PLoS ONE*, *9*(8). https://doi.org/10.1371/journal.pone.0104744

Newell, K. (1986). Constraints on the development of coordination. In M. Wade & H. Whiting (Eds.), *Motor development in children. Aspects of coordination and control* (pp. 341–360). Martinus Nijhoff.

Newell, K. M., & Vaillancourt, D. E. (2001). Dimensional change in motor learning. *Human Movement Science*. https://doi.org/10.1016/S0167-9457(01)00073-2

Renshaw, I., Davids, K., Newcombe, D., & Roberts, W. (2019). *The Constraints-Led Approach: Principles for Sports Coaching and Practice Design*. Routledge.

Reynaud, C. (2011). *Coaching volleyball technical and tactical skills*. Human Kinetics,Champaign, IL.

Ric, A., Hristovski, R., Gonçalves, B., Torres, L., Sampaio, J., & Torrents, C. (2016). Timescales for exploratory tactical behaviour in football small-sided games. *Journal of Sports Sciences*. https://doi.org/10.1080/02640414.2015.1136068

Toyoda, H. (2011). *Volleyball for Beginners. In: FIVB Coach Manual Level I.* (FIVB).

Travassos, B., Vilar, L., Araújo, D., & McGarry, T. (2014). Tactical performance changes with equal vs unequal numbers of players in small-Sided football games. *International Journal of Performance Analysis in Sport*, *14*(2), 594–605. https://doi.org/10.1080/24748668.2014.11868745

Vilar, L., Esteves, P., Travassos, B., Passos, P., Lago-Peñas, C., & Davids, K. (2014). Varying Numbers of Players in Small-Sided Soccer Games Modifies Action Opportunities During Training. *International Journal of Sports Science & Coaching*, *9*(5), 1007–1018.

Wagner, H., Tilp, M., von Duvillard, S. P. V., & Mueller, E. (2009). Kinematic analysis of volleyball spike jump. *International Journal of Sports Medicine*. https://doi.org/10.1055/s-0029-1224177

Zatsiorsky, V., & Kraemer, W. (2006). *Science and practice of strength training* (Second). Human Kinetics,Champaign, IL.

DISCOVER

3.2 Perceptual attunement and meaningful ongoing adjustment group actions increase defensive ball contact effectiveness in volleyball.

Caldeira, P., Paulo, A., Fernandes, O., Infante, J., & Araújo, D. (under submission) Perceptual attunement and meaningful ongoing adjustment group actions increase defensive ball contact effectiveness in volleyball.

3.2.1 Abstract

Defensive situations in volleyball are highly demanding for the players perception-action link due to time constraints. This experimental study aimed to compare perception-action in volleyball defense between a condition characterized by a traditional strategy of pre-play concerted block-defense actions with a condition organized by ongoing perceptual attunement to relevant information. Twelve female elite volleyball players were studied in both conditions (cross-over design) and frequencies of ball contact were compared with those of competition. Additionally, synchronization tendencies were calculated for both conditions as well as for successful and unsuccessful plays. Chi-square test was used to compare group frequencies of defense ball contact to an expected value (i.e., competition frequencies) and *t*-tests were used to compare measures of group synchronization, calculated by Cluster Phase Analyses. Results show that group attunement to relevant information promotes significantly higher frequencies of defense ball contact than pre-determined strategies of action. High values of synchronization were found for both conditions. Successful plays are associated with ongoing adjustments in group synchronization. Results also suggest that over rely on pre-determined block-defense actions limits team goal-achievement in defensive situations. We conclude that group synchronization must be attuned and responsive to local and changing constraints.

Keywords: Ecological dynamics, perceptual attunement, collective behaviour, volleyball

3.2.2. Introduction

In volleyball defense, athletes try to intercept a ball which can travel at 90-100 km/h (Forthomme et al., 2005). This is a very challenging task for players perception-action coupling. In volleyball defense, a traditional strategy to cope with the limited time to act is to concert actions before the opponent's attack. The athletes responsible for blocking (high defense) inform the players responsible for the low defense, which areas of the field they will "cover", before the beginning of the play (FIVB, 2002). However, this strategy may not be effective in many circumstances, given the fast speed of the ball and the characteristics of its flight which are only revealed when the opponents initiate their attacking actions, i.e., independently of what was pre-defined by the defending team. Therefore, it is important to understand and develop the adaptive characteristics of individual and group behavior.

The ecological dynamics theoretical approach situates the adaptive behavior of players at the level of the performer-environment system (Duarte Araújo et al., 2019). Adaptive behavior, defined as the online adjustment of actions directed to an objective in a specific context, is regulated by perception-action couplings. The individual and the environment are coupled by detected information (visual, acoustic and haptic) and by action kinetics (Warren, 2006). Perception-action coupling to achieve a given task goal can be improved over time, due to attunement. Perceptual attunement corresponds to the process of directing attention to sources of information relevant to task goal achievement. With training, athletes move from perceiving sources of information partially relevant to those that are more relevant and useful according to task demands (Davids et al., 2012). Training athlete's perception by orienting visual attention has been explored in laboratory settings usually resorting to video recordings of specific sports scenarios (Abernethy & Wood, 2001; Hagemann et al., 2006). However, within a Constraints-led Approach (CLA) to training and skill acquisition (Davids et al., 2003), task manipulations (i.e., specific constraints) guides the athletes to explore functional solutions. Therefore, in CLA, highlighting relevant sources of information is a manipulation that intends to educate the attention (by amplifying information) of the athletes in representative training tasks. In representative task design, constraints must allow the athletes to couple their actions to key sources of information that are present in the performance-context (Pinder et al., 2011).

In terms of a team, to achieve success, the team synergetic behaviour relies on players' functional adaptive behaviours to each other's' actions guided by the perception of shared affordances (Araújo et al., 2015). However, the efficacy of such specific online attunement and adjustment was never contrasted with the efficacy of a pre-planned action from a team.

From an ecological dynamics perspective, collective variables and specific analytical tools have been used to capture teams' functional behaviour resulting from players interpersonal synergies (Araújo, 2016). For example, there are measures of synchronization (e.g., cluster phase analysis) among player-ball-goal angles in soccer (Carrilho et al., 2020), and lateral and longitudinal synchronization of players in soccer (Duarte et al., 2013) and volleyball (Ramos et al., 2020). Particularly in volleyball, Ramos et.al (2020) implemented a combined constraints-led and step-game approaches to study team synchronization tendencies during counterattack throughout the competitive season and in different moments of the set. Results showed that synchronization tends to diminish with increased tactical complexity and from the beginning to the end of the set. However, synchronization levels changed according to specific contexts (e.g., critical game moments to win or lose), confirming the importance of adjusting and attending to local constraints to understand team's collective behaviour. With this theoretical basis, and empirical evidence towards its relevance, the aim of the present study was to compare the team's defensive effectiveness to contact the ball between a condition characterized by the traditional strategy in volleyball of concerting actions before the opponents attack and the condition characterized by ongoing collective attunement to relevant information. Additionally, to understand possible explanatory processes, we captured tendencies of group synchronization in plays both when the defending team achieved ball contact and when they did not.

3.2.3 Methods

Sample

The participants were 12 female expert volleyball players aged 25.08 ± 8.05 years with volleyball play experience of 8.5 ± 8.05 years. All participants were from the same team competing in the Portuguese 1st division (national level) and four have already been selected for the national team (international level). The players were first balanced according to the specific volleyball positions/functions (2 outside hitters; 2 middle blockers; 2 setters 2 liberos and 2 opposite hitters) they usually play and then randomly assigned to one of two groups. A cross-over design was implemented and both groups played in both "pre-determined" and "free defense" conditions. The study was approved by the Ethics Council of the Faculty of Human Kinetics, University of Lisbon. Participants were informed of the study procedures and gave oral consent.

Experimental task

A volleyball defensive task was implemented (figure 3.6 a) starting with a “free-ball” tossed by the coach to the attacking court. Then, the players in the attacking half-court (setter and three attackers) would organize an attack play with three possible zones to attack (zone 2, 3 and 4). In the “pre-determined” condition the groups were instructed to act has they usually train and play, that is, with pre-determined block coverage (before every play the blockers signal the defense which part of the court they will cover) and defense movements were according to block signaling. In the “free defense” condition, groups were instructed not to pre-determine block coverage and to move freely in defense. However, in this situation the trunk, forearm and hitting hand of the attackers as well as the forearms and hands of the blockers were highlighted with luminous colorful tape (figure 3.6 b).

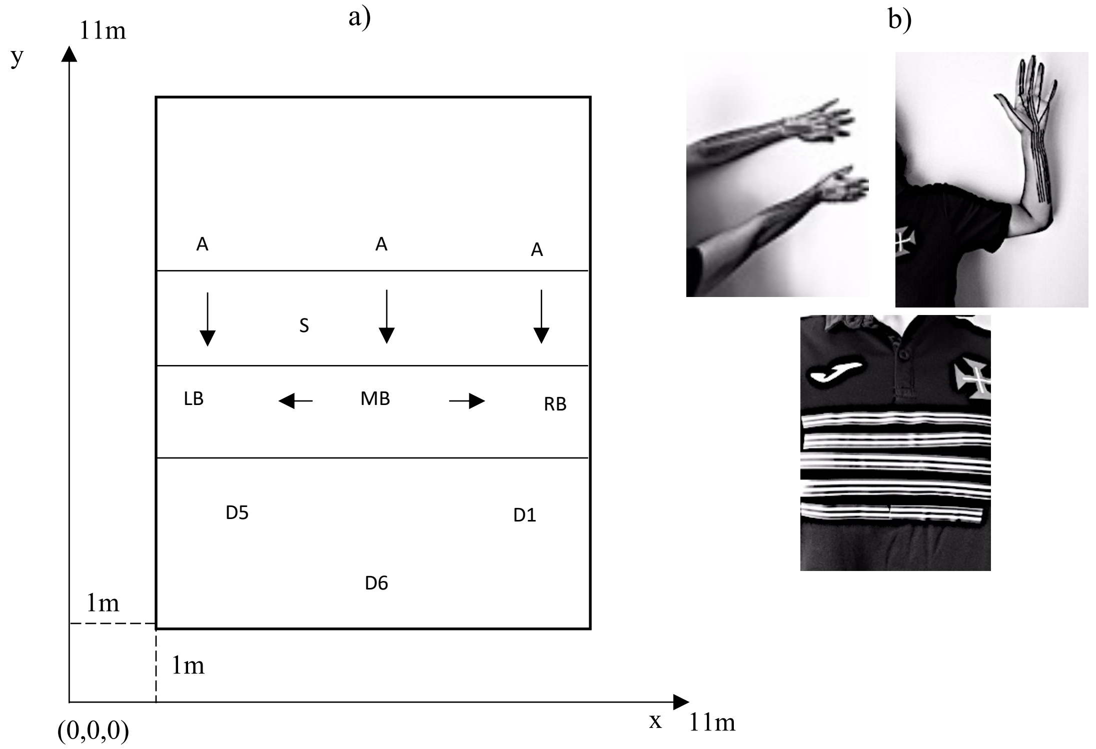


Figure 3. 6 Experimental set-up.

a) The court with the net in the middle, separating the attacking from the defending teams. The attackers (A) and setter (S) organize an attack play with three possible attack zones after a free toss from the coach. The defending team is represented by the blockers (LB, MB, RB) and the defenders (D1, D5; D6).

b) Attackers and blockers highlighted with colorful tape trunk, forearms and hands in the free condition.

Each of the two groups defended 30 attacks in the pre-determined condition and 30 attacks in the free defense condition (cross-over design), in a total of 120 trials, i.e., 60 trials in the pre-determined condition and 60 trials in the free defense condition. To quantify efficacy, only effective attacks (i.e., over the net inside court without touching the blockers) were accounted. Finally, 60 similar situations from formal competition of these teams were selected for analyses. Similarity was assessed by the authors of this study with experience in volleyball match analysis and coaching.

3D Reconstruction

Two cameras were used to record the experimental task at frame rate of 25 Hz. The software Labbio6.2.15 was used to determine 2D coordinates of the ball and players' movement (Serrano & Fernades, 2011). Next, from the 2D coordinates, 3D world coordinates were computed using DLT algorithms in MATLAB R2015a (Reinschmidt, 1994). The measurement volume was calibrated using reference 50 points (11 x 20 x 4). Videos from both cameras were synchronized at the moment of ball contact by the setter and positions of the defensive players were obtained by following their movement between both feet. Also, 2D coordinates at the moment of ball contact in the attack were taken (hand of the attacker contacting the ball and hands of the blockers). Ten trials from the pre-determined and 9 from free defence conditions were excluded from analysis due to tracking difficulties. To estimate the error associated with the conversion from 2D to 3D coordinates (x, y and z) 50 known points were compared with real measures. The median error was 0.25 cm with interquartile range (IQR) of 7 cm and a maximum error of 34 cm in one data point. Six plays were digitalized twice, and coefficient of reliability (R) and technical error of measurement (TEM) (Goto & Mascie-Taylor, 2007) were used to assess intra-observer accuracy and reliability. Results depicted good levels for intra-observer accuracy and reliability in the digitalization process (TEM=0.022, R=0.95).

Group Synchronization

Frank and Richardson (2010) adapted the Kuramoto parameter (Kuramoto & Nishikawa, 1987) to capture synchronization measures among more than two people. The method called cluster phase analysis (CPA) allows to determine group synchronization (mean at any point of the time series) as well as the relative phase of each individual to the group (cluster). Since then, CPA has been used to capture synergetic behavior in different team sports (Duarte et al., 2013; Ramos et al., 2020). CPA measures synchrony of the oscillation phases of the elements of a group and by considering players as oscillators, their phase (between 0 and 2 π in the unit circle) is a periodic variable that can be represented in a complex plane. By measuring the phase coherence or amplitude, the cluster phase (i.e., the team) can be calculated obtaining values between 0 (completely unsynchronized) and 1(completely synchronized) (Acebrón et al., 2005; López-Felip et al., 2018). Hilbert transform can be used to obtain oscillation angles in team sports (Duarte et al., 2013) but recently López-Felip and colleagues (2018) demonstrated that by that method, measures of synchrony might not take in to account the specific and local information constraints that guides players actions. Following this advice, and the fact that angle measures can be obtained from spatial temporal data that specify player-environment relationships (Carrilho et al., 2020), we considered in the present study specific constraints of volleyball defense to measure two sets of angles. In a volleyball match, team defensive actions can be divided into two distinct moments. The first moment is when the ball is in the adversary's half-court and defense can only perceive-act without the possibility of contacting the ball. The second moment is after the opponent's attack, when the defending team acts to intercept de ball. Following this reasoning, group synchronization was calculated for both moments with different parameters. The angles Φ (figure 3.7 a) were measured during the time interval from the set to the attack. For all points of the time series before the attack, Φ was calculated from the player current and previous positions with the vertex corresponding to the position of the ball at the moment of the attack. The angles Θ (figure 3.7 b) were measured during the time interval from the attack to the end of the play. For all points of the time series after the attack, Θ was calculated from the player current position and the position of the ball at the end of the play, with the vertex corresponding to the position of the ball at the moment of the attack.

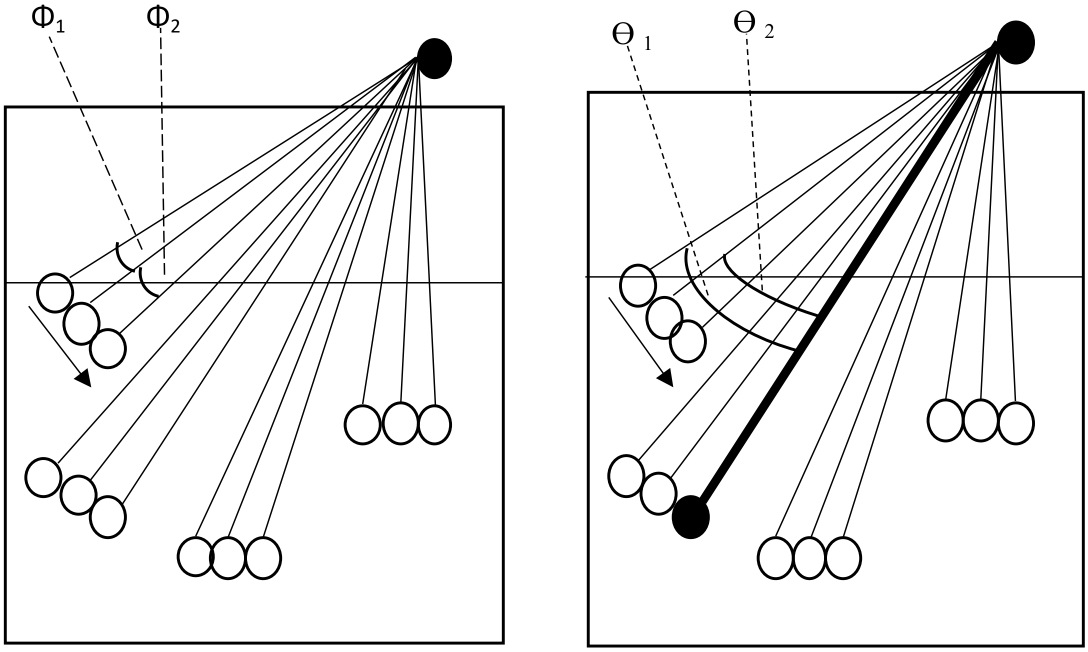


Figure 3. 7 Example of a defensive play with 4 players movement.

a) Before the attack Φ angle calculated from current and previous player (light balls) position with the vertex (black ball) corresponding to the position of the ball at the moment of the attack. b) After the attack Θ angle calculated from player current position and position of the ball at the end of the play with the vertex corresponding to the position of the ball at the moment of the attack.

Variables and analysis

Effectiveness in contact. The first aim of the study was to compare team's defensive effectiveness in contacting the ball between the pre-determined condition of the block-defense and the free defense condition of collectively attending to relevant information (attackers' actions and ball trajectory). To measure effectiveness, we counted the frequencies of contact (CON - one of the defensive players contacted the ball) and non-contact (NONCON - none of the defensive players contacted the ball). Observation instruments (Palao et al., 2006) usually used for volleyball defensive performance were not applied since they involve aspects (i.e., technical proficiency) other than only contact. Chi-square tests were performed to compare frequencies of CON and NONCON in pre-determined and free defense conditions to an expected value. The expected values were CON and NONCON frequencies obtained in 60 trials from formal competition and significance level was set at 0.05.

Process by Group Synchronization. The secondary aim of the study was to address possible explanatory processes by means of group synchronization. For this, we compared group synchronization between defensive plays with ball contact and those plays that did not contact. Group synchronization and distance between players were calculated. Mean_ Sync _Φ expressed the mean of group synchronization before the attack and Mean_ Sync_ϴ expressed the mean of group synchronization after the attack. The mean distances between players were calculated at the moment of the set (Mean_dist_Set), the moment of the attack (Mean_dist_Attack) and at the end of the play (Mean_dist_Final). Mean height of the attack (Mean_HA) and mean height of the block (Mean_HB) were also calculated for pre-determined and free defense group. T-tests were used com compare variables means with significance level set at 0.05. All statical analysis were performed in SPSS26.

3.2.4 Results

Effectiveness

Analysis of the effectiveness in formal competition (*N=60*), revealed f 31 CON and 29 NONCON trials. In the experimental tasks, the pre-determined condition registered 36 CON and 24 NONCON trials, and the free defense condition presented 45 CON and 15 NONCON trial outcomes. Table 3.2 depicts the results of the Chi-square test that was performed to compare frequencies of CON and NONCON to an expected value (formal competition). Pre-determined group was not significantly different from competition *(*X^2*=3.233, p=0.72)* while the free group was significantly different *(*X^2*=16.999, p=0.01)* with higher frequencies of CON and less of NOCON than expected.

Table 3. 2 Comparison of pre-determined and free defense conditions concerning defense contact and noncontact in relation to formal competition.

Category	CON	NONCON	Chi-Square	df	Asimp. Sig.
Competition	31	29	NA	NA	NA
Pre-determined	36	24	3.233	1	0.72
Free defense	45	15	16.999	1	0.01*

* p≤0.05

Spatial-temporal and group synchronization

No significantly differences were found for mean height of the attack (*t (105) =1.116, p=0.26*) and mean height of the block (*t (105) =0.220, p=0.82*) when comparing pre-determined and free defense conditions. Mean distance between players and group synchronization were analysed from 50 trials in the pre-determined condition and 51 trials in the free defense condition (table 3.3). There were no differences between conditions for group synchronization before the attack nor distances between players at the moment of the set, the attack and the end of the play. Group synchronization between conditions was significantly different after the attack *(*$t_{(99)}$ *=2,708, p=0.05)*, with the free defense condition expressing lower values of synchronization.

Table 3. 3 Comparison of mean group synchronization and distances between pre-determined and free defence conditions

	Pre-determined	Free	*p*
Mean_ Sync _Φ	0.87 ± 0.09	0.84 ± 0.08	0.135
Mean_ Sync _ϴ	0.90 ± 0.07	0.86 ± 0.07	0.05*
Mean_dist_Set	5.40 ± 0.43	5.40 ± 0.33	0.915
Mean_dist_Attack	4.81 ± 0.64	4.82 ± 0.59	0.891
Mean_dist_Final	4.33 ± 0.55	4.45 ± 0.55	0.300

* $p \leq 0.05$

Mean_Sync_Φ – mean and standard deviation value of group synchronization before the attack; Mean_ Sync_ϴ - mean and standard deviation value of group synchronization after the attack; Mean_dist_Set – mean and standard deviation distances between players at the moment of the set; Mean_dist_Attack – mean and standard deviation distances between players at the moment of the attack; Mean_dist_Final – mean and standard deviation distances between players at the end of the play

Paired-samples t-test was used to compare synchronization before and after the attack of all the trials (*N*=101, CON *N*=71, NONCON *N*=30) (figure 3.8). Results ($t_{(29)} = -0.340$, *p=0.737)* show that in NONCON trials synchronization does not differ before (0.89±*0.09*) and after the attack *(0.89±0.08)*. For CON trials there is a significantly higher group synchronization ($t_{(70)} = -3.248$, *p=0.05)* after the attack (before = *0.84±0.08* and after = *0.87±0.06*).

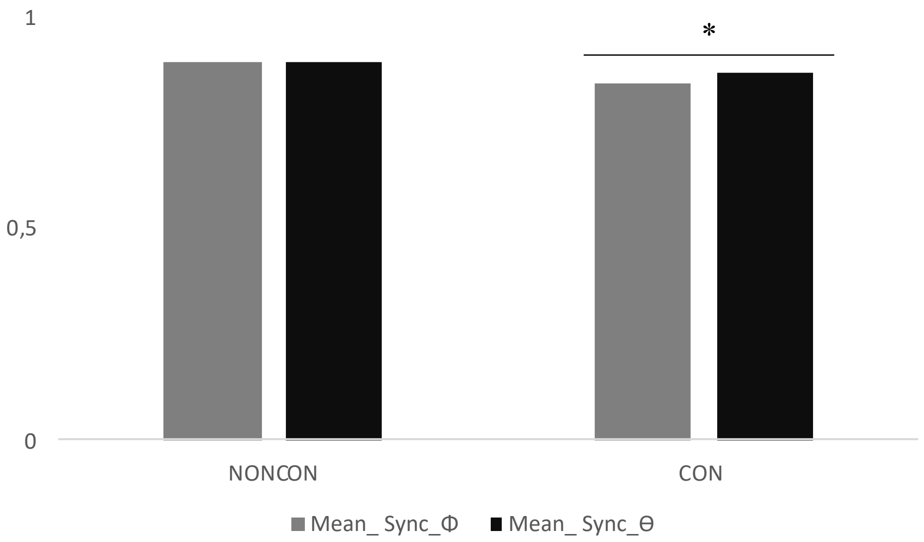


Figure 3. 8 Group synchronization before (Mean_Sync_Φ) and after (Mean_ Sync_Θ) the attack for defensive plays with no ball contact (NONCON) and with ball contact (CON).

* p≤0.05

3.2.5 Discussion

The first aim of the present study was to compare the volleyball team's defensive effectiveness between a pre-determined concerted group behavior and group adjusting to ongoing perceptive attunement to relevant information. In both conditions' relevant contextual elements, such as attack and block height, had no influence given that there were no differences in this cross-over design. Contact and non-contact trials from both pre-determined and free defence conditions were compared, showing that ongoing attunement to relevant information promotes higher frequencies of defensive ball contact than the strategy of block-defense, concerted prior to the attack. Amplifying relevant sources of information in a representative defensive task provided orientation of the athlete's attention that resulted in higher contact frequencies. Perceptual attunement was facilitated by the task constraint of highlighting the trunk, forearm and hitting hand of the attackers as well as the forearms and hands of the blockers.

Only the free defense condition contact and non-contact frequencies were significantly different compared to formal competition frequencies despite these highly experienced players usually train and compete with the conditions of the pre-determined condition. However, their time of experience impacted on their perceptual-motor skills beyond these pre-planned actions. For example, experienced futsal and soccer players show differences in attention orientation revealing that extensive domain-specific practice leads to behavioural specificity (Oppici et al., 2017). Particularly, in volleyball, Afonso et.al. (2012) studied visual search strategies of highly skilled and skilled female players in a defense situation showing that the highly skilled players engage in more visual exploratory behaviour and fixation on functional spaces. In the same vein, the highly trained volleyball players of the present study have the perceptual-motor skills to identify the relevant information in the representative experimental task (Afonso et al., 2012). Relying on perceptual attunement for continually adjust action's without being bound by pre-determined strategies, revealed to be more successful for contacting the ball in these high-level players.

Cluster Phase Analysis revealed high levels of synchronization for both pre-determined and free defence conditions before and after the attack. Importantly, results showed no differences between groups before attack, but also a higher synchronization for the pre-determined condition after the attack. López-Filip et al. (2018) had demonstrated that synchronization per se is not synonymous of team performance since it is possible for players to be completely synchronized (e.g., running in the same direction at the same speed) without any relation with the game goals. The free defense condition without concerting their actions and by attuning to relevant information presented high levels of syncronization (before the attack = 0.84 ± 0.08, after the attack = 0.86 ± 0.07), as it happened with the pre-determined group, but with greater success in contacting the ball. This reveals that such synchronization was adjusted to the specificities of the game.

Moreover, the comparison between before and after the attack showed equivalent levels of synchronization for the NONCON plays. However, there was higher synchronization after the attack for CON plays. These results suggest that success in team´s effectiveness (i.e., contacting the ball) is based on ongoing adaptive behaviour, revealing higher group synchronization as the play unfolds successfully. Changes in group synchronization arise from specific constraints posed by the game (Duarte et al., 2013) confirming that rigid predetermination of group behaviour in volleyball is not desirable (Laporta, Nikolaidis, Thomas, Afonso, 2015). Although, all synchronization values of CON and NONCON plays (before and after the attack) are high, to achieve success, group synchronization must be functional (meaningful) in the current state of affairs and be responsive to changing constraints.

This study has also some limitations that need to be addressed in future research. Namely, the sample of players were from the same team; and only attack zones 2 and 4 were considered for analysis.

3.2.6 Conclusion

In the present study, it was concluded that team attunement to relevant information, but not pre-determined team actions, increased effectiveness in volleyball defending measured by frequencies of ball contact. Not being bound to pre-play concerted actions allowed for a more ongoingly adaptive perception-action process of the defending players leading to more contacts. Measures of group synchronization in pre-determined and free defensive conditions as well as in plays with and without ball contact revealed that local constraints and game dynamics have to be taken into account in practice designs. These findings are according to the perspective of individual-environment system coupled by the reciprocal process of perception-action (Araújo et al., 2019) and can inform coaches about an ecological dynamics approach to practice design (Davids et al., 2012).

.

3.2.7 References:

Abernethy, B., & Wood, J. M. (2001). Do generalized visual training programmes for sport really work? An experimental investigation. *Journal of Sports Sciences*, *19*(3). https://doi.org/10.1080/026404101750095376

Acebrón, J. A., Bonilla, L. L., Vicente, C. J. P., Ritort, F., & Spigler, R. (2005). The Kuramoto model: A simple paradigm for synchronization phenomena. *Reviews of Modern Physics*. https://doi.org/10.1103/RevModPhys.77.137

Afonso, J., Garganta, J., McRobert, A., Williams, A. M., & Mesquita, I. (2012). The perceptual cognitive processes underpinning skilled performance in volleyball: Evidence from eye-movements and verbal reports of thinking involving an in situ representative task. *Journal of Sports Science and Medicine*, *11*(2), 339–345. https://doi.org/S/N

Araújo, D. (2016). Capturing the Complexity of Team Synergies to Provide a Better Practice. *Research Quarterly for Exercise and Sport*, *87*(sup1), S10–S11. https://doi.org/10.1080/02701367.2016.1200414

Araújo, D., Silva, P., & Davids, K. (2015). Capturing group tactical behaviors in expert team players. In D. Baker & D. Farrow (Eds.), *Routlegde Handbook of Sport Expertise* (pp. 209–220). Routledge.

Araújo, Duarte, Hristovski, R., Seifert, L., Carvalho, J., & Davids, K. (2019). Ecological cognition: expert decision-making behaviour in sport. In *International Review of Sport and Exercise Psychology*. https://doi.org/10.1080/1750984X.2017.1349826

Carrilho, D., Couceiro, M. S., Brito, J., Figueiredo, P., Lopes, R. J., & Araújo, D. (2020). Using optical tracking system data to measure team synergic behavior: Synchronization of player-ball-goal angles in a football match. *Sensors (Switzerland)*, *20*(17), 1–14. https://doi.org/10.3390/s20174990

Davids, K., Araújo, D., Hristovski, R., Passos, P., & Chow, J. Y. (2012). Ecological dynamics and motor learning design in sport. *Skill Acquisition in Sport: Research, Theory and Practice*, *March*, 112–130. https://doi.org/10.13140/RG.2.1.2297.0089

Davids, K., Araújo, D., Shuttleworth, R., & Button, C. (2003). Acquiring Skill in Sport: A Constraints-Led Perspective. *International Journal of Computer Science in Sport*, *2*, 31–39.

Duarte, R., Araújo, D., Correia, V., Davids, K., Marques, P., & Richardson, M. J. (2013). Competing together: Assessing the dynamics of team-team and player-team synchrony in professional association football. *Human Movement Science*, *32*(4), 555–566. https://doi.org/10.1016/j.humov.2013.01.011

FIVB. (2002). *Top Volley: TECHNICAL BOOKLET Men's Game, Technique and Tactics*. FÉDÉRATION INTERNATIONALE DE VOLLEYBALL.

Forthomme, B., Croisier, J. L., Ciccarone, G., Crielaard, J. M., & Cloes, M. (2005). Factors correlated with volleyball spike velocity. *American Journal of Sports Medicine*, *33*(10), 1513–1519. https://doi.org/10.1177/0363546505274935

Goto, R., & Mascie-Taylor, C. G. N. (2007). Precision of measurement as a component of human variation. *Journal of Physiological Anthropology*, *26*(2), 253–256. https://doi.org/10.2114/jpa2.26.253

Hagemann, N., Strauss, B., & Cañal-Bruland, R. (2006). Training perceptual skill by orienting visual attention. *Journal of Sport and Exercise Psychology*, *28*(2). https://doi.org/10.1123/jsep.28.2.143

Kuramoto, Y., & Nishikawa, I. (1987). Statistical macrodynamics of large dynamical systems. Case of a phase transition in oscillator communities. *Journal of Statistical Physics*. https://doi.org/10.1007/BF01009349

Laporta, L Nikolaidis , P, Thomas, L, Afonso, J. (2015). Attack Coverage in High-Level Men’s Volleyball: Organization on the Edge of Chaos? *Journal of Human Kinetics*, *47*(October), 249–257. https://doi.org/10.1515/hukin-2015-0080

López-Felip, M. A., Davis, T. J., Frank, T. D., & Dixon, J. A. (2018). A cluster phase analysis for collective behavior in team sports. *Human Movement Science*, *59*(November 2017), 96–111. https://doi.org/10.1016/j.humov.2018.03.013

Oppici, L., Panchuk, D., Serpiello, F. R., & Farrow, D. (2017). *Long-term Practice with Domain-Specific Task Constraints Influences Perceptual Skills*. *8*(August), 1–9. https://doi.org/10.3389/fpsyg.2017.01387

Palao, J. M., Santos, J., & Urena, A. (2006). Effect of reception and dig efficacy on spile performance and manner of execution in volleyball. *Journal of Human Movement Studies*, *51*(4), 221–238. https://doi.org/10.1017/CBO9781107415324.004

Pinder, R. a, Davids, K., Renshaw, I., & Araújo, D. (2011). Representative learning design and functionality of research and practice in sport. *Journal of Sport & Exercise Psychology*, *33*(1), 146–155.

Ramos, A., Coutinho, P., Ribeiro, J., Fernandes, O., Davids, K., & Mesquita, I. (2020). Increasing tactical complexity to enhance the synchronisation of collective behaviours: An action-research study throughout a competitive volleyball season. *Journal of Sports Sciences*. https://doi.org/10.1080/02640414.2020.1794265

Reinschmidt, C. (1994). *Reconstruction of 3D Coordinates with the Use Local Camera Coordinates and the DLT Coefficients for the n Cameras* (1.1). The University of Calgary.

Serrano, J., & Fernades, O. (2011). Reliability of a new method to analyse and to quantify athletes’ displacement. *Rev. Port.Cien. Desp.*, *11*, 935–936.

Warren, W. H. (2006). The dynamics of perception and action. *Psychological Review*, *113*(2), 358–389. https://doi.org/10.1037/0033-295X.113.2.358

EXPLOIT

3.3 Functional variability facilitates goal-achievement in volleyball attack: an ecological dynamics approach

---

Caldeira, P., Paulo, A., Veloso, A., Infante, J., & Araújo, D. (under submission) Functional variability facilitates goal-achievement in volleyball attack: an ecological dynamics approach.

3.3.1 Abstract

From an ecological dynamics approach the careful manipulation of task constraints amplifies functional movement variability. This is called the constraints-led approach (CLA). Inducing functional variability indicates that the performer explores movement degeneracy, accommodating changing task constraints and finding movement solutions to achieve task goal. The present study analysed the relationship of CLA and traditional blocked training practice with success in volleyball attack with block opposition.

The study was conducted with young male volleyball players that were randomly assign to either a Traditional Approach (TA) or Constraints-led Approach (CLA) group. Spatial-temporal whole movement variables from the attackers were captured to analyse if accommodating task constraints by movement degeneracy could increase successful attacks in volleyball. Binomial logistic regression was used to relate the spatial-temporal variables with the percentage of successful attacks.

After a 6-week intervention programme, the CLA group showed significantly higher percentage of success in attack actions, when facing the opposition's block. The final binomial logistic regression model retained the variables lateral deviation of the players center of mass from group average at the planting step and longitudinal deviation of the players center of mass from group average at ball contact as predictors of success. We conclude that to overcome the block in volleyball infusing functional variability in task design, as advocated by CLA, promotes superior performance, and that movement degeneracy to accommodate constraints is predictive of success in volleyball attack.

Keywords: Constraints-led approach; task variability; movement degeneracy

3.3.2 Introduction

Traditional theories of learning explain motor learning based on an information-processing, computational process. From this perspective, expertise is achieved by the frequent repetition of an ideal technique until it become stable or programmed and performed automatically [1,2]. To these objectives, practice that we consider traditional is often organized by blocks where all trials of one training condition are performed before switching to another [3]. However, a growing body of research has shown that learning and performance enhancement are supported in nonlinear processes where exploratory motor behaviour is crucial to achieve functional solutions to goal-directed movement tasks [4]. These findings are explained by an ecological dynamic's theoretical framework [5]. To understand behaviour under this perspective we must attend to the functionality of the reciprocity between performer and performance environment [6] and how learning evolves through the process of training [7]. Ecological dynamics developed the notion of representative task design, i.e., how coaches carefully manipulate constraints and task affordances that learners explore finding their own functional movement solutions [8].

CLA pedagogical principles provide learning and training opportunities that encourage self-organization of behaviour under constraints [9], induce variability in representative task design [10–12] promote information-movement couplings, support adaptive development and empower performers to explore functional solutions [13,14]. CLA is based on exploratory behaviour, where the athlete initially searches for task solutions that are stabilized by attuning to task relevant information sources. Functional task variability potentiates the formation of movement synergies or coordinative structures facilitating task goal achievement [15,16]. By manipulating constraints in the exercises practiced during the training session, coaches promote skill learning and performance, as it was shown in different sports [17]. For example, Fitzpatrick and colleagues (2018) compared match-play and tennis-specific skills between scaled task constraints, such as court dimensions, rules and scoring format, and a traditional approach in young tennis players. After an 8-week training programme, the scaled constraints group was more symmetrical in stroke performance (backhands vs forehands), decreased their errors (less 14.9% in backhand strokes) and had higher scores on the tennis specific skill test [18]. In the present study, we aimed to compare the effects of a traditional blocked approach and the constraints-led approach on attack performance with block opposition in volleyball. In addition to the attack outcome, spatial-temporal variables of the players movements were analyzed to determine if exploration of the movement degeneracy was related to successful attacks.

3.3.3 Methods

Participants

Twelve male 17 years old volleyball players who play at national (9 players) and international level (3 players) participated in the study and were randomly assign to either a Traditional Approach (TA) or Constraints-led Approach (CLA) group. Table 3.5 presents the characterization of both groups in terms of height, weight and years of volleyball experience. Independent samples t-test revealed no differences between groups for height (*t (10) = 0.773, p=0.47*), weight (*t (10) = -0.379, p=0.71*) and experience (*t (10) = -0.659, p=0.52*). The significance level was set *a priori* *p*<0.05. This study was approved by the Ethics Council of the Faculty of Human Kinetics, University of Lisbon.

Table 3. 4 Comparison of the TA and CLA groups with respect to height, weight and volleyball experience

Group	*N*	Height (m)	Weight (kg)	Experience (years)
TA	6	1.81 ± 0.33	71.16 ± 2.78	4.83 ± 0.88
CLA	6	1.79 ± 0.40	71.66 ± 1.63	5.16 ± 0.75

p<0.05 for all variables

Experimental design

Attack performance was evaluated in three moments: before the intervention (t1), after the intervention (t2) and in a follow-up test (t3) performed 3 weeks after the post-test. In a game like situation (i.e., attack after serve-reception-set, see Figure 3.9) each group, in each moment, performed a total of 108 attacks of zone 4 with block opposition. Each player performed 18 attacks, one at a time, to avoid fatigue. The maximum number of blockers in each trial was two. The players did not know the type of block coverage they would face since they were presented randomly. Although presented randomly to the attackers, the order of block actions was previously defined and informed to the blockers before each trial.

Intervention procedure

Both TA and CLA groups trained for 6 weeks (2 times a week) zone 4 attack facing three types of block opposition, typical to the game of volleyball (Figure 3.9). The block situations presented were line coverage, diagonal coverage or "open block" (i.e., with space between the two blockers). The TA trials were performed in blocked practice, i.e., players performed the attack to each opposition block over and over, knowing previously what type of opposition to expect, before they move to the next opposition block, repeating it over and over, until they finally perform the last of the three block situations in the same way. The CLA trained the same three block situations randomly, not knowing which opposition block would occur at each trial. However, both groups performed in the same task settings the same number of trials. Throughout the six-week intervention each player from either group performed 48 trials facing each block opposition situation in a total of 144 trials.

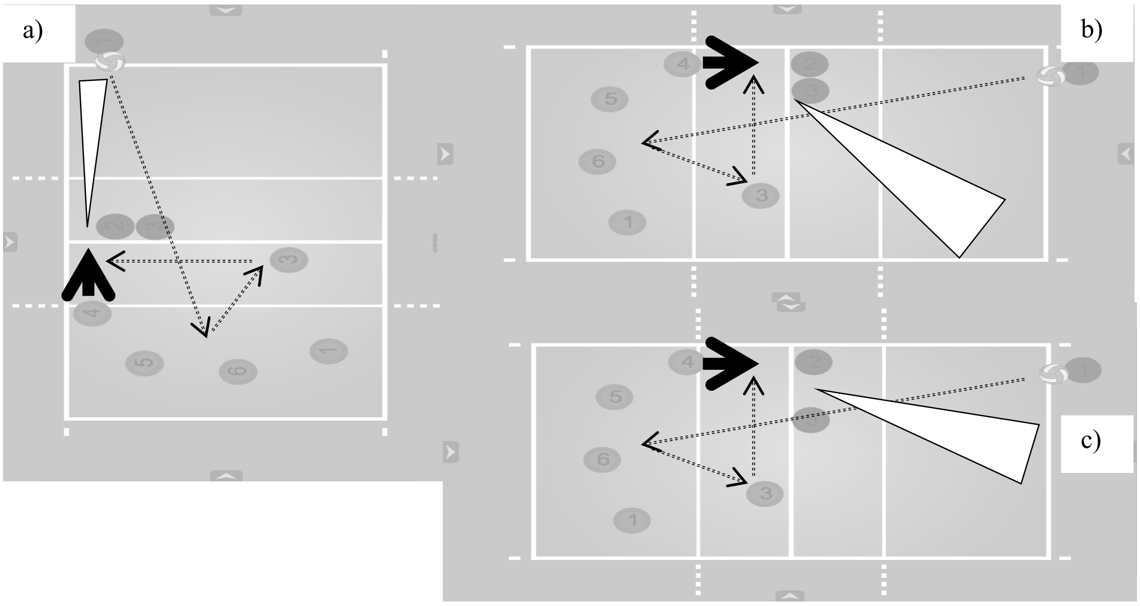


Figure 3. 9 Intervention task: The players identified with numbers perform zone 4 attack (bold arrow) from serve-reception-set. Ball trajectory (dashed arrow). The type of opposition provides a preferable target area (white triangle) to successfully overcome the block. Court a) represents the task with block covering diagonal. Court b) represents the task with block covering the line. Court c) represents the task with "open block". Each court represents the attack with a type of block opposition.

Dependent variables

Attack performance. The first aim of the study was to compare the effects of the CLA and a TA on the attack performance of the outside hitter. Successful attack was defined as the spikes that overcome the block and landed inside the court. Percentage of Successful Attack Actions ($\%S_{AA}$) was the variable considered for analysis.

Spatial-temporal variables. The second aim of the study was to observe if attack performance was related to movement degeneracy. To that effect the deviation from the group average of six spatial-temporal variables was calculated. The horizontal approach in volleyball (figure 3.10) can be divided in the phases of "orientation step", "planting step" and "take-off" [19]. Considering the end of planting step (EPS) and the moment of ball contact (BC) as well as lateral, longitudinal and vertical planes (figure 3.10), the spatial-temporal variables considered were lateral, longitudinal and height deviation of the players center of mass from group average at EPS (X_EPS, Y_EPS, Z_EPS) and lateral, longitudinal and height deviation of the players center of mass from group average at BC (X_BC, Y_BC, Z_BC).

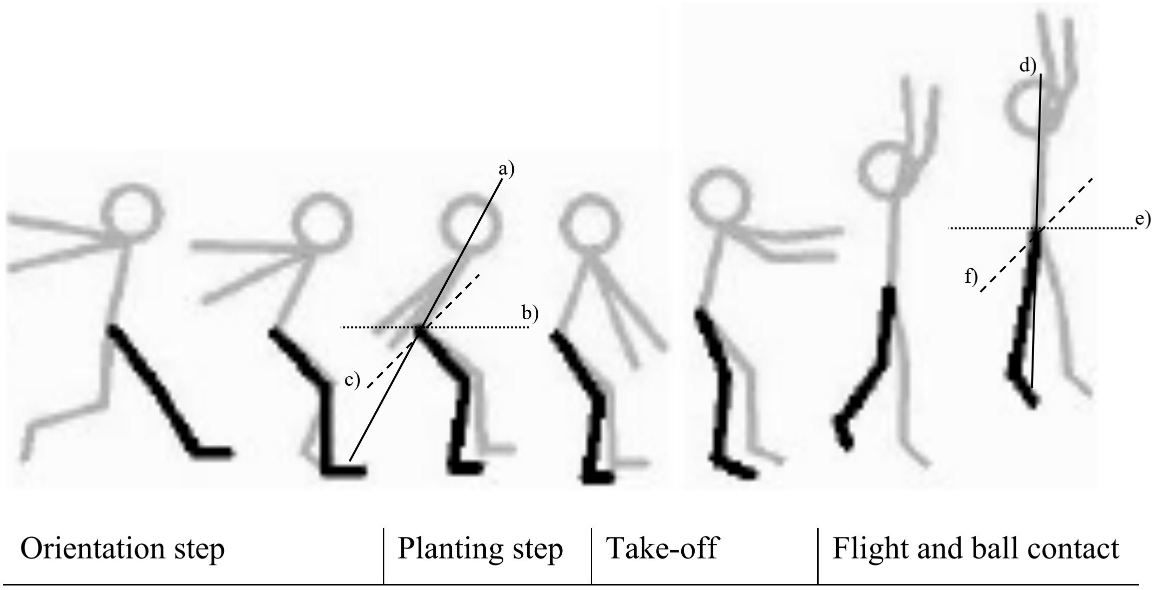


Figure 3. 10 Horizontal approach (orientation step, planting step and take-off), flight and ball contact. a) vertical plane at the end of the planting step, b) longitudinal plane at the end of the planting step, c) lateral plane at the end of the planting step, d) vertical plane at ball contact, e) longitudinal plane at ball contact, f) lateral plane at ball contact.

Data collection and analysis

Two cameras were used to record the three tests at a frame rate of 50Hz. One hundred and eight attacks (18 each player) of each group at each test were observed to determine attack performance. Repeated measures ANOVA was used to compare between and within groups. Percentage of Successful Attack Actions (%S_{AA}) were compared between and within groups with a significance level of 0.05. Effect size (Cohen's *d*) with a correction factor for samples <50 [20] was computed regarding between groups (at t1, t2 and t3) and within groups (t1 to t2; t2 to t3 and t1 to t3).

Twenty-five videos of successful and 25 unsuccessful attacks from both TA and CLA groups were randomly selected and the motion capture system Ariel Performance Analysis System (APAS) [21,22] was used to extract the spatial-temporal variables. The procedures to conduct the analysis in APAS were: video trimming to synchronize videos of both cameras; calibration using 20 points of known points resorting to a meterstick, with 5 markers in height (0m, 1m, 2m, 3m and 4m) in 4 different court locations; digitalization in each frame of 16 anatomical points of the attacker (left/right foot, left/right ankle, left/right knee, left/right hip, left/right shoulder, left/right elbow, left/right fist, left/right hand), 2 anatomical points of the blockers (middle blocker left hand and zone 2 blocker right hand) and the ball; APAS 3D- Linear Transformation software was used to extract real coordinates and a 4ºorder low pass filter (Hamming window) with a cutoff frequency of 5Hz for coordinates X, Y and Z was applied. Six attacks were digitalized twice and coefficient of reliability (R) and technical error of measurement (TEM) [23] were used to assess intra-observer accuracy and reliability. Results depicted good levels for intra-observer accuracy and reliability in the digitalization process (TEM=0.09, R=0.99). Binomial logistic regression was used to relate the spatial-temporal variables with successful attacks. All variables were first included and a manual backward stepwise was used to remove those who did not contribute to best predictive model. In logistic regression models the variables units have significant impact in their expression in the model. Thus, since all spatial-temporal variables considered range was less than 1m, the values were entered in the model in decimeters. Final model was then selected according to procedures followed in previous studies [24]. Significance level was set at 0.05. To further confirm the discriminant power of the model, we performed a ROC curve analysis [25]. The results of the ROC analysis were interpreted as follows: Area under the curve [AUC] <0.70, low discriminant accuracy; AUC in the range of 0.70–0.90, moderate discriminant accuracy; and AUC ≥0.90, high discriminant accuracy [26].

3.3.4 Results

Attack performance

Attack performance at t1, t2 and t3 are presented in Figure 3.11. After the intervention, the percentage of S_{AA} was significantly higher in the CLA group (*F (1,34) =4.173, p=0.05*) compared with TA group. At t1 $\%S_{AA}$ was equal for both groups. At t2, $\%S_{AA}$ was higher in the CLA group than TA group with a moderate effect size (*d*=0.5 SD) and at t3 $\%S_{AA}$ was also higher in the CLA group than TA group with a moderate effect size between groups (*d*=0.5 SD). There was no significant difference within groups.

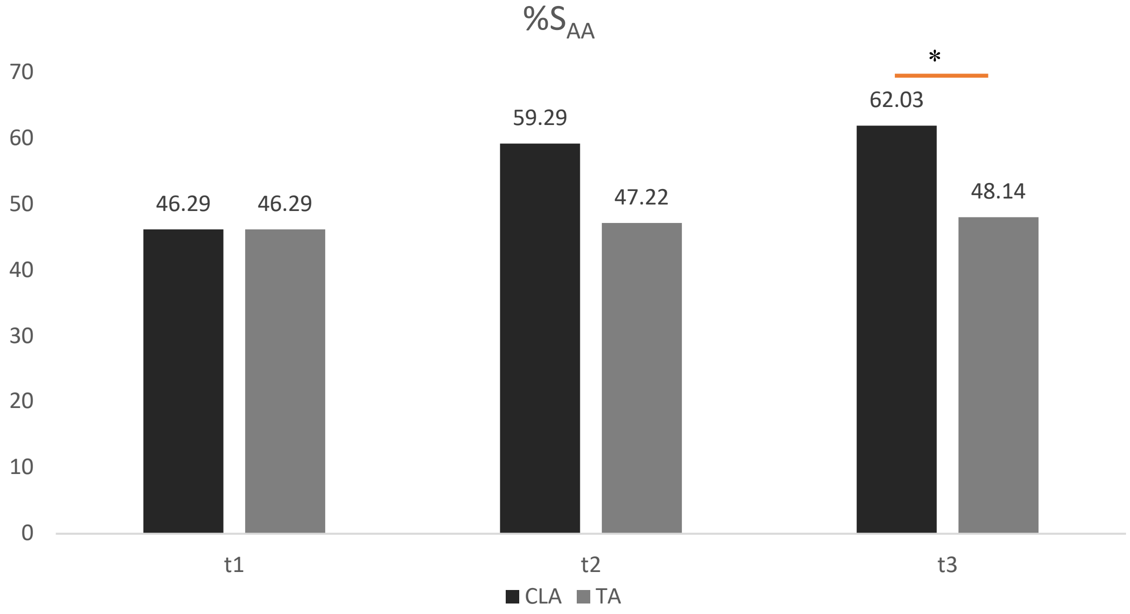


Figure 3. 11 Percentage of successful attack actions ($\%S_{AA}$). t1 - before the intervention; t2 - after the intervention; t3 - follow-up test. CLA = Constraint-led Approach. TA = Traditional Approach.

* Significant difference p≤0.05.

Movement degeneracy

The final model of attack performance was achieved by first entering all the considered spatial-temporal variables (X_EPS, Y_EPS, Z_EPS and X_BC, Y_BC, Z_BC) depicted in table 3.5 and step by step removing those who did not contribute significantly to the prediction of the outcome (table 3.6).

Table 3. 5 Spatial-temporal variables entering the logistic regression model. Values in decimeters.

Variable	Minimum	Maximum	Mean	Std. deviation
X_EPS (dm)	0.00	0.85	0.206	0.185
Y_EPS (dm)	0.02	0.55	0.187	0.128
Z_EPS (dm)	0.00	0.89	0.078	0.129
X_BC (dm)	0.00	0.87	0.156	0.147
Y_BC (dm)	0.01	0.62	.0189	0.154
Z_BC (dm)	0.00	0.20	0.060	0.523

Note. X_EPS – lateral deviation of the players center of mass from group average at the end of the planting step; Y_EPS – longitudinal deviation of the players center of mass from group average at the end of the planting step; Z_EPS – height deviation of the players center of mass from group average at the end of the planting step; X_BC - lateral deviation of the players center of mass from group average at ball contact; Y_BC - longitudinal deviation of the players center of mass from group average at ball contact; Z_BC – height deviation of the players center of mass from group average at ball contact.

A sample of 50 attacks was considered for analysis: 25 successful attacks and 25 unsuccessful according to the same criteria used to analyze %S_{AA}. The final model retained X_EPS and Y_BC as predictor variables. The model performed significantly better than the constant only model ($G^2_{N=50} = 10.410, p=.005$), satisfying goodness-of-fit criteria ($X^2_{N=50} = 3.822, p=0.873$), resulting in a Nagelkerke r^2 of 0.25 (modest effect). The model classified correctly 19 of 25 unsuccessful attacks (76%) and 16 of 25 successful attacks (64%) with an overall correct classification of 70%. The ROC analysis revealed a moderate discriminant accuracy of the model (AUC=.75 p=.003; 95%CI [.61,.89]). According to our model, an increase of one unit (1dm) in X_EPS will heighten in 62% the chances of a successful attack, and a one-unit decrease (1dm) in Y_BC will heighten in 39% the chances of a successful attack.

Table 3. 6 Final logistic regression model of attack performance

	B (SE)	*p*	Exp(*B*)	EXP(*B*) 95% C.I.	
X_EPS (dm)	0.484 (0.208)	0.020	1.623	1.080	2.439
Y_BC (dm)	-0.496 (0.234)	0.034	0.609	0.385	0.963
Constant	-0.019 (0.572)	0.973	0.981		

Note. X_EPS – lateral deviation of the players center of mass from group average at the end of the planting step; Y_BC - longitudinal deviation of the players center of mass from group average at ball contact.

3.3.5 Discussion

The present study aimed to compare the effects of the traditional blocked approach and the constraints-led approach in volleyball attack with block opposition. After a 6-week intervention the CLA group showed a significant improvement in attack performance compared to the TA. Importantly, both groups had the same $\%S_{AA}$ at pre-test and while the CLA group performed better in the subsequent tests (post and follow-up), the TA had also a marginally increase in performance.

The volleyball attack involves intercepting the ball in the air, hitting with power and accuracy while avoiding obstacles such as the net and the opposition block. The task manipulation implemented for the CLA group allowed a more representative training context, supporting the athletes exploratory action guided by performance environment information. Pinder et.al. (2011) had previously illustrated the importance of representative task design in cricket batters when they analyzed batting responses either to a “live” bowler or a ball projection machine. The use of the projection machine withdrew key environmental information (i.e., bowler’s actions before ball release) from the context, leading to an increased difficulty of the batters to regulate their own actions [27]. In our task manipulation for the CLA group, the task variability provided by the unknown, but yet limited, actions of the block, guided the athletes to be perceptually attuned to the blockers’ actions, and channel them to find functional movement solutions under changing constraints. An important aspect of the task manipulation was to limit the number of block actions and by doing so it was provided a simplification (rather than a decomposition) of the task, while maintaining relevant information of the competition context [28]. Given the task design that facilitates the coupling of attacker’s movements to relevant information sources (i.e., block actions), solutions emerged according to specific constraints in an individualized manner. The 3 block situations of the experimental task have theoretically 'optimal' recommended solutions (figure 3.9), however, visual observation from post and follow-up tests revealed that players went beyond those recommended solutions to overcome the opposition (e.g., attacking a sharp diagonal with diagonal block coverage). Presumably, perceptual attunement to block actions also increased movement degeneracy. In volleyball serve-reception, it was previously showed that players act according to local constraints instead of the theoretical 'optimal solution' [24] and the same seams to apply to the attack.

A second aim of the study was to determine if movement degeneracy predicts successful attacks. The analysis of spatial-temporal variables of players movement (lateral, longitudinal and height deviation of the players center of mass from group average) we found that variability at the end of the planting step and consistency at ball contact increased the chances of a successful attack. Observation of figure 3.12 highlights how lateral variability of players center of mass at the end of the planting step (X_EPS) and longitudinal consistency of players center of mass at ball contact (Y_BC) are predictive of successful attacks and an inverse relation exists for unsuccessful attacks. These findings suggest that under changing constraints (i.e., different block actions), attackers, in order to contact the ball at a preferable location to overcome the block, have to be adaptive in their motor solutions.

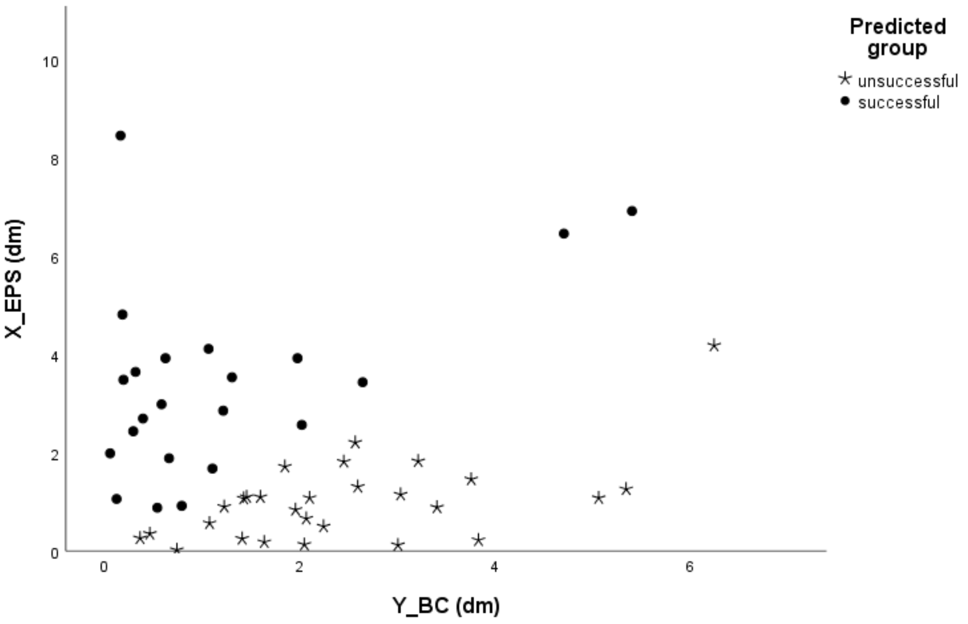


Figure 3. 12 Model's predicted group membership for attack performance with respect to X_EPS (lateral deviation of the players center of mass from group average at the end of the planting step) and Y_BC (longitudinal deviation of the players center of mass from group average at ball contact) values.

Bernstein's work (1996) on how the human movement system dynamically (re)organizes degrees of freedom to provide the necessary consistency and variability to meet task demands has been posteriorly verified in sports related complex motor skills ^{29}. Recently, Glanzer et.al. (2019) studied in baseball pitchers, at the individual's level of analysis, measuring the variability of 20 kinematic parameters and consistency of pitch location. Consistency of most kinematic parameters and shoulder horizontal abduction variability predicted higher consistency of pitch location 30. In the present study, in a group level of analysis, variability of one spatial-temporal variable (X_EPS) predicted a successful outcome of the attack. This may be because the block actions guide the players' movements. When an attacker goes through the horizontal approach to hit the ball, the block actions only vary in height or laterally (see figure 3.9 to visualize lateral differences between block actions). Attacking over the block would involve a large difference in high between point of ball contact by the attacker and the blockers hands, which leaves lateral adjustment as the preferable movement adaptive strategy.

A limitation of the present study was that only attack from zone 4 was analyzed and attacks from other zones are usually performed with different, usually faster, tempos. Also, defense was not included in testing procedures making analyses of successful attacks only related to overcoming the block opposition. Another limitation was the number of trials per attacker, not allowing an additional individual level of analysis of movement degeneracy.

3.3.6 Conclusion

In conclusion, CLA has been shown to promote better skill learning than traditional approaches in several sports [17]. The findings of the present study align with previous research, indicating that inducing functionally constrained variability in task design as advocated by CLA allows volleyball players to explore system degeneracy promoting superior effective goal achievement when compared to previously known tasks design (constraints). Practicing attack tasks with unknown yet limited number of block actions resulted in higher performance than separately repeating known scenarios of block opposition. Successful attacks can be predicted by lateral variability of the centre of mass of the attacker at the end of the planting step and longitudinal consistency at the instant of ball contact.

3.3.7 References

1. Gentile AM. A working model of skill acquisition with application to teaching. *Quest*. 1972;17:3-23.
2. Schmidt R a. R. A Schema Theory of Discrete Motor Skill Learning. *Psychological review*. 1975;82(4):225-260. doi:10.1037/h0076770
3. Schmidt R, Wrisberg C. *Motor Learning and Performance*. Human Kinetics,Champaign, IL; 2000.
4. Button C, Lee CM, Mazumder AD, Tan WKC, Chow J. Empirical Investigations of Nonlinear Motor Learning. *The Open Sports Sciences Journal*. 2012;5:49-58. doi:10.2174/1875399X01205010049
5. Button C, Seifert L, Chow J, Davids K, Araújo D. *Dynamics of Skill Acquisition: An Ecological Dynamics Approach*. Human Kinetics,Champaign, IL; 2020.
6. Araújo D, Davids K, Hristovski R. The ecological dynamics of decision making in sport. *Psychology of Sport and Exercise*. 2006;7(6):653-676. doi:10.1016/j.psychsport.2006.07.002

7. Chow JY, Davids K, Hristovski R, Araújo D, Passos P. Nonlinear pedagogy: Learning design for self-organizing neurobiological systems. *New Ideas in Psychology*. 2011;29(2):189-200. doi:10.1016/j.newideapsych.2010.10.001
8. Pinder R a, Davids K, Renshaw I, Araújo D. Manipulating informational constraints shapes movement reorganization in interceptive actions. *Attention, perception & psychophysics*. 2011;73(4):1242-1254. doi:10.3758/s13414-011-0102-1
9. Chow JY, Davids K, Button C, Renshaw I. *Nonlinear Pedagogy in Skill Acquisition An Introduction*. (Routledge, ed.).; 2016.
10. Barris S, Davids K, Farrow D. Representative learning design in springboard diving: Is dry-land training representative of a pool dive? *European journal of sport science*. 2013;13(6):638-645. doi:10.1080/17461391.2013.770923
11. Davids K, Araújo D, Shuttleworth R, Button C. Acquiring Skill in Sport: A Constraints-Led Perspective. *International Journal of Computer Science in Sport*. 2003;2:31-39.
12. Verhoeff W, Millar S, Oldham A, Cronin J. Coaching the Power Clean: A Constraints-Led Approach. *Strength and Conditioning Journal*. Published online 2019. doi:10.1519/SSC.0000000000000508
13. Button C, Chow J-Y, Rein R. Exploring the perceptual-motor workspace: New approaches to skill acquisition and training. In: *Routledge Handbook of Biomechanics and Human Movement Science.* Routledge.; 2008.
14. Renshaw I, Yi Chow J, Davids K, Hammond J, Hammond J. A constraints-led perspective to understanding skill acquisition and game play: a basis for integration of motor learning theory and physical education praxis? *Physical Education & Sport Pedagogy*. 2010;9(2):1-21. doi:10.1080/17408980902791586
15. Davids K, Bartlett R, Glazier P, Araújo D. Movement Systems as Dynamical Systems. 2003;33(4):245-260.
16. Davids K, Bennett S, Newell K. *Movement System Variability*. Human Kinetics,Champaign, IL; 2006.
17. Clark ME, McEwan K, Christie CJ. The effectiveness of constraints-led training on skill development in interceptive sports: A systematic review. *International Journal of Sports Science and Coaching*. 2019;14(2):229-240. doi:10.1177/1747954118812461
18. Fitzpatrick A, Davids K, Stone JA. Effects of scaling task constraints on emergent behaviours in children ’ s racquet sports performance. *Human Movement Science*. 2018;58(October 2017):80-87. doi:10.1016/j.humov.2018.01.007

19. Wagner H, Tilp M, von Duvillard SPV, Mueller E. Kinematic analysis of volleyball spike jump. *International Journal of Sports Medicine*. Published online 2009. doi:10.1055/s-0029-1224177

20. Durlak JA. How to select, calculate, and interpret effect sizes. *Journal of Pediatric Psychology*. Published online 2009. doi:10.1093/jpepsy/jsp004

21. Klein PJ, DeHaven JJ. Accuracy of three-dimensional linear and angular estimates obtained with the ariel performance analysis system. *Archives of Physical Medicine and Rehabilitation*. Published online 1995. doi:10.1016/S0003-9993(95)80028-X

22. Richards JG. The measurement of human motion: A comparison of commercially available systems. *Human Movement Science*. Published online 1999. doi:10.1016/S0167-9457(99)00023-8

23. Goto R, Mascie-Taylor CGN. Precision of measurement as a component of human variation. *Journal of Physiological Anthropology*. 2007;26(2):253-256. doi:10.2114/jpa2.26.253

24. Paulo A, Zaal FTJM, Fonseca S, Araújo D. Predicting volleyball serve-reception. *Frontiers in Psychology*. 2016;7(NOV). doi:10.3389/fpsyg.2016.01694

25. Tabachnick BG, Fidell LS. *Using Multivariate Statistics (6th Ed.)*.; 2012.

26. Swets JA. Signal detection theory and ROC analysis in psychology and diagnostics : collected papers. In: *Scientific Psychology Series*. ; 1996.

27. Pinder RA, Davids K, Renshaw I, Araújo D. Manipulating informational constraints shapes movement reorganization in interceptive actions. *Attention, Perception, and Psychophysics*. 2011;73(4):1242-1254. doi:10.3758/s13414-011-0102-1

28. Davids K, Bennett S, Handford C, Jones B. Acquiring coordination in self-paced, extrinsic timing tasks: A constraints-led perspective. *International Journal of Sport Psychology*. 1999;30(4):437-461. http://apps.webofknowledge.com/full_record.do?product=UA&search_mode=GeneralSearch&qid=45&SID=3FpOgJvwnjJ4yduuMzJ&page=1&doc=1

29. Seifert L, Wattebled L, Herault R, et al. Neurobiological degeneracy and affordance perception support functional intra-individual variability of inter-limb coordination during ice climbing. *PLoS ONE*. 2014;9(2). doi:10.1371/journal.pone.0089865

30. Glanzer JA, Diffendaffer AZ, Slowik JS, Drogosz M, Lo NJ, Fleisig GS. The relationship between variability in baseball pitching kinematics and consistency in pitch location. *Sports Biomechanics*. 2019;00(00):1-8. doi:10.1080/14763141.2019.1642378

4 General Discussion

4.1 General discussion

Grounding the present thesis on an ecological dynamic's framework allowed to pursuit our efforts, theoretical and experimental, on a broader perspective that offers an understanding of the reciprocal relation of the individual and the environment. This perspective is rooted on concepts of direct perception (Gibson, 1979), perception-action coupling (Warren, 2006), nonlinear self-organized behaviour (Kelso, 1995) and whole-body process of synergetic motor solutions (Bernstein, 1996; Turvey & Fonseca, 2014). These concepts were fairly unpacked and explored in the papers that form this thesis. Specifically, in the theorical papers presented in sub-chapters 2.2 and 2.3 a position statement and novel hypothesis were presented to expanded on the role of biotensegrity structures in individual and collective synergetic behaviour. In the paper "*Neurobiological tensegrity: The basis for understanding inter-individual variations in task performance?"* (sub-chapter 2.2*)* we draw from the work of Bernstein (1996) and Turvey and Fonseca (2014) to propose that tensegrity properties in human structures might be the basis of variations in task performance. To that intent, we reviewed concepts of tensegrity (Fuller, 1962), haptic perception (Turvey & Fonseca, 2014), systems degeneracy (Seifert et al., 2016) and metastability (Kelso, 2012). Our theoretical research aimed to suggest that each individual has a unique tensegrity system, and this uniqueness shapes functionality in performer-environment systems. In the paper "*Linking Tensegrity to Sports Teams Collective Behaviors: Towards the Group-tensegrity Hypothesis"* (sub-chapter 2.3) the concept of tensegrity was for the first time considered beyond the internal universe of each individual into the topic of sports team's collective behaviour. We advance the hypothesis that informationally connected components of a system (i.e., players in a team) could behave as a larger tensegrity system and have the efficiency of their collective behaviour predicted on tensegrity properties. Overall, our theoretical contribution advanced new perspectives at some of the core concepts of the ecological approach to synergetic adaptive behaviour and reviewed fundamental concepts of CLA providing examples of its application to volleyball (sub-chapter 2.1).

The applicable framework (CLA) that is supported by ecological dynamics and Newell (1986) work of constraints on the development of coordination was implemented in experimental settings aiming to confirm the efficacy on volleyball performance. We address the main findings of the experimental studies following the order of chapter 3.

4.2 Overview of the main experimental findings

4.2.1 Search: education of intentions promoting a convergency of task goals with the learner’s goals.

Accommodating individual differences in the training process is a hallmark of the CLA (Renshaw et al., 2019) that can be challenging to implement in a team setting. In the study presented in sub-chapter 3.1 we aimed to compare the effects of training the volleyball spike accuracy accommodating individual differences (i.e., initial spike accuracy performance) and to analyze re-organization of the time spent and variability of time spent in each phase of the horizontal approach. The results show that accommodating individual differences enhances performance (i.e., spike accuracy) and simplification of task constraints is an effective manipulation in volleyball spike accuracy performance. Additionally, freezing degrees of freedom maintaining high variability in a component of the coordinative structure of the horizontal approach was the strategy of movement re-organization associated with higher spike accuracy. In this study court dimensions were manipulated to create two levels of spatial-temporal demands for the spike training and players were randomly assigned to a training group of where individual performance was considered (individuality in group condition IGC) or a group which considered overall group task goals (general group condition -GGC). A post-test of spike accuracy was conducted five days after the training session and a follow-up test conducted six days after the post-test. The players that trained in court dimensions manipulated according to their initial performance showed significant improvement in spike accuracy in post and follow-up tests. These results highlight that it is possible to accommodate individual differences in a team setting by manipulating tasks constraints. An important principle of the nonlinear pedagogy that informs CLA is that tasks should be simplified rather than decomposed (Chow et al., 2016). The task manipulation implemented respected this principle for both groups with different degrees of simplification.

The time players spent in each phase of the horizontal approach was analysed and compared. Results show that the IGC and GGC adopted different strategies of movement time re-organization. The phases of orientation step, planting step and take-off (Wagner et al., 2009) of the horizontal approach are the coordinative structure that volleyball athletes use to contact the ball in the spike. Both groups changed significantly time of the orientation and planting steps from pre to post intervention, however, only the GGC changed the time spent in the take-off across tests. The IGC stabilized the time spent in the take-off, therefore, reducing the degrees of freedom of the coordinative structure in the phase closer to ball contact. Our data confirms findings of previous studies (Chow et al., 2008) showing that reducing degrees of freedom to improve accuracy in a movement sport is a consequence of practice. However, our results contrasts with findings of temporal organization of movement in baseball showing a progressive reduction of variability up to ball contact (Katsumata, 2007). The IGC reduced degrees of freedom at the take-off maintaining higher variability in the time spent which can attributed to the existence of a subsequent phase (the flight) after the horizontal approach and before contacting the ball. Reducing degrees of freedom seems to be an effective strategy provided that a certain degree of flexibility is maintained.

4.2.2 Discover: identifying the appropriated use of sources of information while exploring task solutions

Perceptual attunement corresponds to the process of identifying sources of information relevant to each situation and when to use them. With training, athletes move from identifying sources of information partially relevant to even more useful ones in game situations (Davids et al., 2012). In the study presented in sub-chapter 3.2 we aimed to compare the team's defensive capacity to contact the ball between using the traditional strategy in volleyball of concerting actions before the opponents attack and using a strategy of ongoing collective attunement to relevant information. Additionally, we aimed to determine tendencies of group synchronization in plays where defense achieved ball contact and plays where defense did not. Results show that collectively attuning to relevant information promotes significant higher frequencies of defense ball contact than pre-determined strategies of action and successful defensive plays are associated with "online" significant changes in group synchronization. In this cross-over design study with expert female players, frequencies of defensive ball contact using pre-determined actions or ongoing collective attunement were compared to an expected value extracted from formal competition. Although these female expert players usually train and play in the pre-determine condition they also developed, trough long-term specific practice, the perceptual skills (Oppici et al., 2017) to easily adapt to the free condition. Nevertheless, relying on acquired perceptual skills without being bound by pre-determined strategies revealed to be more successful for contacting the ball. Cluster Phase Analyses allowed to measure group (i.e., defense players) synchronization before and after the attack and between successful and unsuccessful plays. The data confirms that synchronization per se is not synonymous of team performance (López-Felip et al., 2018). Both groups revealed high levels of synchronization before and after the attack and the pre-determined group showed, despite having less frequencies of ball contacts, a significant higher value, after the attack, than the free group. Interestingly, when comparing synchronization before and after the attack data shows that in successful plays synchronization is significantly higher after the attack. These results suggest that success in team´s goal-achievement (i.e., contacting the ball) is predicted on “online” adaptive behaviour exposed by a significant increase in group synchronization as the play unfolds.

4.2.3 Exploit: calibration enables immediate adaptation to situational task demands

Representative task design is a fundamental concept in ecological dynamics approach to learning and training. Careful manipulation of task constraints and affordances provides the performer the opportunities to explore their own functional movement solutions (Pinder et al., 2011). Also, in the CLA functional task variability potentiates the formation of movement synergies or coordinative structures facilitating task goal achievement (Davids et al., 2006). In the intervention study presented in sub-chapter 3.3, we aimed to compare the effects of a traditional blocked approach (TA) and the constraints-led approach on attack performance with block opposition. In addition to the attack outcome, spatial-temporal variables of the players movements were analyzed to determine if exploration of the movement degeneracy was related to successful attacks. After a 6-week intervention the CLA group showed a significant improvement in attack performance compared to the TA and we found that variability at the end of the planting step and consistency at ball contact increased the chances of a successful attack. The results confirm the previously illustrated importance of representative task design (Pinder et al., 2011). In our task manipulation for the CLA group, the task variability provided by the unknown, but yet limited, actions of the block, guided the athletes to be perceptually attuned to the blockers’ actions, and channel them to find functional movement solutions under changing constraints. By limiting the number of actions of the block the task was simplified (rather than decomposed) while maintaining relevant information of the competition context (Davids et al., 1999). Presumably, perceptual attunement to block actions also increased movement degeneracy. Human movement system re-organizes degrees of freedom to provide the necessary consistency and variability to meet task demands (Bernstein, 1996; Glanzer et al., 2019; Seifert et al., 2014). Accordingly, our data shows that successful attacks were predicted on lateral variability of the players center of mass at the end of the planting step and longitudinal consistency of the players center of mass at ball contact. These findings suggest that under changing constraints (i.e., different block actions), attackers, in order to contact the ball at a preferable location to overcome the block, have to be adaptive in their motor solutions.

Overall, results from the experimental studies suggests that higher levels of performance can be achieved from implementing CLA in volleyball teams. Attack precision, defensive ball contact and success in overcoming block opposition were significantly higher in groups that trained according to CLA principles. Also, results show that individual and collective synergetic behavior are predicted on concepts advocated by ecological dynamics. Freezing degrees of freedom in components of a coordinative structure, “online” regulation of collective behavior and movement degeneracy were highlighted as strategies of synergetic behavior to meet task demands.

4.2 Future research

More questions and the desire of a deeper understanding emerged at the end of this thesis. In our theoretical work on the role of biotensegrity structures on individual and collective synergetic behaviour we suggested that they might be trainable. Future research to address this question would be of great interest considering the possible impact in movement performance. The foreseeable difficulties to address this topic should not preclude taking steps to experimentally test the effects on movement performance of specific stimulus to the whole-body tensegrity network. Namely, stimulus that would increase sensitivity and responsiveness of such structures. Probably even more challenging is to experimentally address the concept of tensegrity in collective behaviour. Nevertheless, we left suggestions (sub-chapter 2.3) regarding which collective variables could be related to tensegrity properties in a sports team collective behaviour.

Implementing CLA, specifically in volleyball, as yet to be fully explored. Our work outcropped is value in specific sub-phases of the game (i.e., attack and defense) but others should also be address. Individual and collective behaviour derived from implementing CLA can be studied in more comprehensive manner. The analysis on the coordinative structure of the horizontal approach that we provided in the study presented in sub-chapter 3.1 would benefit from kinematic data. What specifying variables to attune in different sub-phases of the game is certainly an important issue to explore and representative design with appropriated task variability still needs to be fine-tuned.

4.3 Practical implications

This is a particular important issue considering that the underling objective of this thesis was its usefulness to coaches. Our experimental studies not only implemented CLA but also compare the results against more ingrained approaches to volleyball training. By showing the results of the CLA on performance we hope to, at least, capture the attention of coaches to a new perspective. Respecting individual differences in training proved to be possible and related to increased performance. Coaches can further unveil other strategies to assess individual differences of their players and design representative tasks to address them. Simplifying instead of decomposing tasks is another principle of CLA that coaches can implement with more certainty of positive results in performance. To highlight the importance of collective perceptual attunement over pre-determined actions was an important topic addressed by our work. Although we do not advocate suppressing pre-determined strategies in team training there is prove in the work presented that a focus on collectively attunement to specifying variables will promote superior performance. Coaches are certainly the best agents to identify the specifying variables for every sub-phase of the game and how to train their players to perceptually attune to them. Also, the findings that team synchronization per se is not reflective of performance but requires to be adaptative to changing constraints can be informative to training design. Considering the findings presented in sub-chapter 3.3, coaches can objectively consider task constrained variability as a feature of representative training design. Reducing movement variability and searching for the "ideal" technic has been a hallmark of traditional approaches to skill acquisition (Gentile, 1972; Schmidt, 1975) , however, our findings clearly suggests that training should promote movement variability as an adaptive strategy to changing constraints.

As we previously stated, our theoretical work is open to further research. However, the suggestion that the whole-body tensegrity network can be trained and the possible impacts on movement performance should, at this point, increase coach's awareness to the topic.

5 References

5.1 References:

Afonso, Jose, Esteves, F., Araújo, R., Thomas, L., & Mesquita, I. (2012). Tactical determinants of setting zone in elite men's volleyball. *Journal of Sports Science and Medicine*, *11*(1), 64–70.

Afonso, Jóse, Mesquita, I., Marcelino, R., António, J., Alfonso, J., & Antonio, J. (2010). Analysis of the setter ' s tactical action in high-performance women ' s volleyball. *Kinesiology*, *42*(1), 82–89.

Araújo, D., & Davids, K. (2016). Team synergies in sport: Theory and measures. *Frontiers in Psychology*, *7*(SEP), 1–13. https://doi.org/10.3389/fpsyg.2016.01449

Araújo, D., Silva, P., & Davids, K. (2015). Capturing group tactical behaviors in expert team players. In D. Baker & D. Farrow (Eds.), *Routlegde Handbook of Sport Expertise* (pp. 209–220). Routledge.

Araújo, Duarte. (2006). *Tomada de Decisão no Desporto*. Faculdade de Motricidade Humana.

Araújo, Duarte, Davids, K., & Hristovski, R. (2006). The ecological dynamics of decision making in sport. *Psychology of Sport and Exercise*, *7*(6), 653–676. https://doi.org/10.1016/j.psychsport.2006.07.002

Araújo, Duarte, Davids, K., & Renshaw, I. (2020). Cognition, Emotion and Action in Sport. In *Handbook of Sport Psychology*. https://doi.org/10.1002/9781119568124.ch25

Araújo, Duarte, & Volossovitch, A. (2005). Fundamentos para o treino da tomada de decisão: uma aplicação ao andebol. In Duarte Araújo (Ed.), *A acção táctica no desporto* (pp. 75–97). Visão e Contextos Lda.

Araújo, R. M., Castro, J., Marcelino, R., & Mesquita, I. R. (2010). Relationship between the Opponent Block and the Hitter in Elite Male Volleyball. *Journal of Quantitative Analysis in Sports*, *6*(4), 306–313. https://doi.org/10.2202/1559-0410.1216

Bernstein, N. A. (1996). On the construction of movements. In M. L. Latash & M. T. Turvey (Eds.), *On dexterity and its development*. Mahwah, NJ: Erlbaum. https://doi.org/10.1007/s13398-014-0173-7.2

Button, C., Chow, J.-Y., & Rein, R. (2008). Exploring the perceptual-motor workspace: New approaches to skill acquisition and training. In *Routledge handbook of biomechanics and human movement science.* Routledge.

Chow, J. Y. (2013). Nonlinear Learning Underpinning Pedagogy: Evidence, Challenges, and Implications. *Quest*, *65*(4), 469–484. https://doi.org/10.1080/00336297.2013.807746

Chow, J. Y., Davids, K., Button, C., & Koh, M. (2008). Coordination changes in a discrete multi-articular action as a function of practice. *Acta Psychologica*, *127*(1), 163–176. https://doi.org/10.1016/j.actpsy.2007.04.002

Chow, J. Y., Davids, K., Button, C., & Renshaw, I. (2016). *Nonlinear Pedagogy in Skill Acquisition An Introduction* (Routledge, Ed.).

Chow, J. Y., Davids, K., Button, C., Shuttleworth, R., Renshaw, I., & Araujo, D. (2007). The Role of Nonlinear Pedagogy in Physical Education. *Review of Educational Research*, *77*(3), 251-278 ST-The Role of Nonlinear Pedagogy in Ph. https://doi.org/10.3102/003465430305615

Correia, V., Carvalho, J., Araújo, D., Pereira, E., & Davids, K. (2019). Principles of nonlinear pedagogy in sport practice. *Physical Education and Sport Pedagogy*. https://doi.org/10.1080/17408989.2018.1552673

Davids, K, Bennett, S., Handford, C., & Jones, B. (1999). Acquiring coordination in self-paced, extrinsic timing tasks: A constraints-led perspective. In *International Journal of Sport Psychology* (Vol. 30, Issue 4, pp. 437–461). http://apps.webofknowledge.com/full_record.do?product=UA&search_mode=GeneralSearch&qid=45&SID=3FpOgJvwnjJ4yduuMzJ&page=1&doc=1

Davids, K., Bennett, S., & Newell, K. (2006). *Movement System Variability*. Human Kinetics,Champaign, IL.

Davids, K, Button, C., Araujo, D., Renshaw, I., & Hristovski, R. (2006). Movement models from sports provide representative task constraints for studying adaptive behavior in human movement systems. *Adaptative Behaviour*, *14*(1), 73–95. https://doi.org/10.1177/105971230601400103

Davids, Keith, Araújo, D., Hristovski, R., Passos, P., & Chow, J. Y. (2012). Ecological dynamics and motor learning design in sport. *Skill Acquisition in Sport: Research, Theory and Practice*, *March*, 416. https://doi.org/10.13140/RG.2.1.2297.0089

Davids, Keith, Araújo, D., Shuttleworth, R., & Button, C. (2003). Acquiring Skill in Sport: A Constraints-Led Perspective. *International Journal of Computer Science in Sport*, *2*, 31–39.

Davids, Keith, Button, C., & Bennett, S. (1999). Modeling Human Motor Systems in Nonlinear Dynamics: Intentionality and Discrete Movement Behaviors. *Nonlinear*

Dynamics, Psychology, and Life Sciences. https://doi.org/10.1023/A:1022429522099

Fuller, R. (1962). *Tensile-integrity structures.* (Patent No. 3,063,521).

Gentile, A. M. (1972). A working model of skill acquisition with application to teaching. *Quest*, *17*, 3–23.

Gibson, J. J. (1979). The Ecological Approach to Visual Perception. In *Houghton Mifflin- Boston*.

Glanzer, J. A., Diffendaffer, A. Z., Slowik, J. S., Drogosz, M., Lo, N. J., & Fleisig, G. S. (2019). The relationship between variability in baseball pitching kinematics and consistency in pitch location. *Sports Biomechanics*, *00*(00), 1–8. https://doi.org/10.1080/14763141.2019.1642378

Jacobs, D. M., & Michaels, C. F. (2007). Direct Learning. *Ecological Psychology*, *19*(4), 321–349. https://doi.org/10.1080/10407410701432337

Juan, S. H., & Mirats Tur, J. M. (2008). Tensegrity frameworks: Static analysis review. *Mechanism and Machine Theory*, *43*(7), 859–881. https://doi.org/10.1016/j.mechmachtheory.2007.06.010

Katsumata, H. (2007). A functional modulation for timing a movement: A coordinative structure in baseball hitting. *Human Movement Science*, *26*(1), 27–47. https://doi.org/10.1016/j.humov.2006.09.005

Kelso, J. (1995). *Dynamics patterns: the self-organization of brain and behavior*. MIT Press.

Kelso, J. A. (2012). Multistability and metastability: Understanding dynamic coordination in the brain. In *Philosophical Transactions of the Royal Society B: Biological Sciences*. https://doi.org/10.1098/rstb.2011.0351

Liu, Y.-T., Mayer-Kress, G., & Newell, K. M. (2006). Qualitative and quantitative change in the dynamics of motor learning. *Journal of Experimental Psychology. Human Perception and Performance*, *32*(2), 380–393. https://doi.org/10.1037/0096-1523.32.2.380

López-Felip, M. A., Davis, T. J., Frank, T. D., & Dixon, J. A. (2018). A cluster phase analysis for collective behavior in team sports. *Human Movement Science*, *59*(November 2017), 96–111. https://doi.org/10.1016/j.humov.2018.03.013

Newell, K. (1986). Constraints on the development of coordination. In *Motor development in children: aspects of coordination and control* (pp. 341–260). https://doi.org/10.1016/S0166-4115(08)62541-8

Newell, K. M., & Corcos, D. M. (1993). Issues in variability and motor control. In K. Newell & Corcos DM (Eds.), *Variability and motor control.* (pp. 1–12). Human Kinetics,Champaign, IL.

Newell, K. M., Liu, Y. T., & Mayer-Kress, G. (2001). Time scales in motor learning and development. *Psychological Review*, *108*(1), 57–82. https://doi.org/10.1037//0033-295X

Oppici, L., Panchuk, D., Serpiello, F. R., & Farrow, D. (2017). *Long-term Practice with Domain-Specific Task Constraints Influences Perceptual Skills*. *8*(August), 1–9. https://doi.org/10.3389/fpsyg.2017.01387

Paulo, A., Zaal, F. T. J. M., Fonseca, S., & Araújo, D. (2016). Predicting volleyball serve-reception. *Frontiers in Psychology*, *7*(NOV). https://doi.org/10.3389/fpsyg.2016.01694

Pinder, R. A., Davids, K., Renshaw, I., & Araújo, D. (2011). Manipulating informational constraints shapes movement reorganization in interceptive actions. *Attention, Perception, and Psychophysics*, *73*(4), 1242–1254. https://doi.org/10.3758/s13414-011-0102-1

Renshaw, I., Araújo, D., Button, C., Chow, J. Y., Davids, K., & Moy, B. (2015). Why the Constraints-Led Approach is not Teaching Games for Understanding: a clarification. *Physical Education and Sport Pedagogy*, *8989*(October), 1–22. https://doi.org/10.1080/17408989.2015.1095870

Renshaw, I., Davids, K., Newcombe, D., & Roberts, W. (2019). *The Constraints-Led Approach: Principles for Sports Coaching and Practice Design*. Routledge.

Renshaw, I., Yi Chow, J., Davids, K., Hammond, J., & Hammond, J. (2010). A constraints-led perspective to understanding skill acquisition and game play: a basis for integration of motor learning theory and physical education praxis? *Physical Education & Sport Pedagogy*, *9*(2), 1–21. https://doi.org/10.1080/17408980902791586

Scarr, G. (2014). *Biotensegrity: The structural basis of life*. Handspring Publishing.

Schmidt, R. a. R. (1975). A Schema Theory of Discrete Motor Skill Learning. *Psychological Review*, *82*(4), 225–260. https://doi.org/10.1037/h0076770

Seifert, L., Komar, J., Araújo, D., & Davids, K. (2016). Neurobiological degeneracy: A key property for functional adaptations of perception and action to constraints. *Neuroscience and Biobehavioral Reviews*, *69*, 159–165. https://doi.org/10.1016/j.neubiorev.2016.08.006

Seifert, L., Komar, J., Barbosa, T., Toussaint, H., Millet, G., & Davids, K. (2014). Coordination Pattern Variability Provides Functional Adaptations to Constraints in Swimming Performance. *Sports Medicine*, 1333–1345. https://doi.org/10.1007/s40279-014-0210-x

Serra-Olivares, J., & García-Rubio, J. (2017). La problemática táctica, clave en el diseño representativo de tareas desde el enfoque de la pedagogía no lineal aplicada al deporte. *Retos*, *32*, 278–280.

Turvey, M. T., & Fonseca, S. T. (2014). The Medium of Haptic Perception: A Tensegrity Hypothesis. *Journal of Motor Behavior*, *46*(3), 143–187. https://doi.org/10.1080/00222895.2013.798252

Wagner, H., Tilp, M., von Duvillard, S. P. V., & Mueller, E. (2009). Kinematic analysis of volleyball spike jump. *International Journal of Sports Medicine*. https://doi.org/10.1055/s-0029-1224177

Warren, W. H. (2006). The dynamics of perception and action. *Psychological Review*, *113*(2), 358–389. https://doi.org/10.1037/0033-295X.113.2.358

6 Appendixes

6.1 Appendixes 1 – Ethical Council Approvement

FACULDADE DE MOTRICIDADE HUMANA

Conselho de Ética
para a Investigação

Para:

Dr. Paulo Caldeira
Faculdade de Motricidade Humana

Data: 22 de maio de 2018

Projeto: "Constraints-led Approach and Synergetic Behaviour in Volleyball Performance"

Estado CEFMH: Positivo
Parecer CEFMH N.º: 10/2018

Este Conselho analisou o projeto em epígrafe. Confirma-se que o mesmo está em conformidade com as diretrizes nacionais e internacionais para a investigação científica que envolve seres humanos, incluindo a Declaração de Helsínquia sobre os Princípios Éticos para a Investigação Médica em Seres Humanos (2013) e a Convenção sobre os Direitos do Homem e a Biomedicina ("Convenção de Oviedo", 1997).

O Presidente do Conselho de Ética para a Investigação da FMH

Paulo A. S. Armada da Silva