INSTITUTO POLITÉCNICO DE SANTARÉM
Escola Superior de Desporto de Rio Maior

POLITÉCNICO
DE SANTARÉM

Fitness and Sports Performance in Badminton Athletes: Assessment of Fitness Markers and Their Relationship with Badminton Sports Performance

Dissertação

Mestrado em Atividade Física e Saúde

André Rafael de Cabrita Pito

Orientador: Professor Doutor Nuno Manuel Queiroz Pimenta de Magalhães

Janeiro de 2025

Agradecimentos (Acknowledgements)

Gostaria de expressar a mais profunda gratidão a todos os intervenientes que contribuíram de alguma forma para a conclusão da presente tese. Sem a vossa colaboração, encorajamento e apoio, este trabalho não teria sido possível.

Em primeiro lugar, os meus agradecimentos vão para o meu orientador, o Professor Doutor ***Nuno Manuel Pimenta*** *pelo seu constante apoio e orientação durante todo o processo, bem como todos os ensinamentos de grande valor que me transmitiu durante todo este tempo, e também pela amizade, incentivo e confiança que depositou em mim de modo que o presente trabalho fosse concluído com a qualidade que ambos alvejávamos. Em segundo lugar agradeço ao professor* ***Jorge Cação*** *pela sua contribuição através do seu vasto conhecimento na área do badminton e das suas sugestões extremamente pertinentes no decorrer do trabalho. Agradeço também ao professor* ***Rafael Oliveira*** *e professor* ***Renato Fernandes*** *pelo apoio prestado no decorrer das recolhas.*

Agradeço à instituição ***Escola Superior de Desporto de Rio Maior*** *do* ***Instituto Politécnico de Santarém,*** *por me ter acolhido durante grande parte do meu percurso académico (licenciatura e mestrado), por todas as vivências, experiências e aprendizagens que me proporcionou e por todo o apoio institucional prestado na elaboração desta tese. Agradeço também à* ***Federação Portuguesa de Badminton*** *na pessoa do* ***Diogo Silva*** *(Selecionador Nacional),* ***Fernando Silva*** *(Selecionador Nacional) e* ***José Eduardo Nunes*** *(Preparador Físico da Seleção Nacional) por me permitirem realizar a recolha num dos seus estágios e pelo acompanhamento, planeamento e ajuda no decorrer do mesmo.*

Um agradecimento especial a todos os envolvidos neste projeto, em especial ao colega ***Miguel Madeira*** *pela sua colaboração na revisão e à minha amiga e colega de mestrado* ***Ana Barnabé*** *por toda a motivação e espírito de entreajuda praticado.*

Por último, mas nunca menos importante quero agradecer à minha família e amigos, em especial aos meus pais – ***Paula*** *e* ***Alexandre*** *por toda a compreensão, incentivo e amor que demonstraram ao longo de toda a minha vida e em especial, no decorrer da elaboração desta tese.*

List of Abbreviations

ACL – Anterior Cruciate Ligament

ACMJ – Akimbo Countermovement Jump

AHD – Acromio-Humeral Distance

ap – back and forth displacement difference

BDNF – Brain-Derived Neurotrophic Factor

BF – Body Fat

BI – Bioeletrical Impedance

BM – Body Mass

BMI – Body Mass Index

BOT-2 – *BruininksOseretzky* Test

BRIT – Badminton Reaction Inhibition Test

BSRT – Badminton Specific Reaction Time

BST – Badminton-Specific Speed Test

CAD – Composite Angular Diference

CG – Control Group

CKUCEST – Closed Kinetic Chain Upper Extremity Stability Test

COD – Change of Direction

COP – Centre of Pressure

CMJ – Countermovement Jump

DAP – Dominant Anterior-posterior

DENDE – Dominant Extension vs Non-Dominant Extension Ratio

DENDF – Dominant Flexion vs Non-Dominant Flexion Ratio)

DML – Dominant Medial-lateral

DOMS – Delayed Onset Muscle Soreness

DPSI – Dynamic Posture Stability Index

ECW/TBW – Extracellular Water to Total Body Water Ratio

EMS – Electromyostimulation

ER – External Rotation

ExG – Experimental Group

Ex_L – Extension Left

Ex_R – Extension Right

FSC – Flemish Sports Compass

FM – Fat Mass

FFM – Fat Free Mass

Fl_L – Flexion Left

Fl_R – Flexion Right

HG – High-Risk Group

HHD – Hand-Held Dynamometer

INT – Integrated Neuromuscular Training

IR – Internal Rotation

Kg – Kilogram

Kg/m2 – Kilogram per squared meter

KJOC – Kerlan Jobe Orthopaedic Clinical Score

KTK – *KörperkoordinationsTest für Kinder*

l – Litre

LFCM – Low Fat Chocolate Milk Group

LG – Low-Risk Group

M – Meters

MHR – Maximum Heart Rate

min – Minute

ml – Millilitre

ML – left-right displacement difference

MRSAB – Multiple Repeated Sprint Ability

NDAP – Non-Dominant Anterior-posterior

NDML – Non-Dominant Medial-lateral

PB – Balance-Plyometric

pl – total displacement distance

PT – Plyometric

PTT – Plate Tapping Test

PRISMA-ScR – Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews

RAST – Running Anaerobic Sprint Test

RPE – Rate of Perceived Exertion

RSI – Reactive Strength Index

RIT – Reaction Initiation Training

SAT – Standard Arrowhead Agility Test

sBDNF – Serum Brain-Derived Neurotrophic Factor

SBJ – Standing Broad Jump

SEMO – Standard Southeast Missouri

SJ – Squat Jump

SMBT – Sitting Medicine Ball Throw Test

SMM – Skeletal Muscle Mass

SPJ – Spike Jump

SR – Shuttle Run

SRAT – Shuttle Run Agility Test

TTE – Time to Exhaustion

VJ – Vertical Jump

VJH – Vertical Jump Height

Vo2 Max – Maximal Oxygen Uptake

YBT – Y Balance Test

Dissertation Abstract

The current dissertation includes three original investigations focused on the assessment of fitness markers and their relationship with badminton sports performance.

The first study of this dissertation is a scoping review and aimed to summarize and analyse the current literature regarding which tests are predominantly used to assess each of the different fitness markers (agility, balance, body composition, cardiovascular endurance, coordination, flexibility, muscular endurance, power, reaction time, speed, and strength) in badminton players. The results obtained showed that only some markers presented some level of consistency in the assessment tools used, while the vast majority lacked consistency and robustness.

The second study aimed to carry out an assessment and characterization of the Portuguese national team elite badminton players regarding four markers of fitness (agility, body composition, power, and cardiovascular endurance), as well as biosocial data, and to compare the results with data from the current existing literature. The assessment of fitness markers is still inconsistent and diverse. This makes the process of comparing findings and extracting valid conclusions harder. Working on standardizing fitness testing in badminton players would allow for an improvement in the sport and serve as a basis for deeper and more meaningful investigations in the future. The publication of reference values for elite Portuguese badminton players aims to increase the available literature and may contribute to a more scientific based approach to training while providing accessible tools that can be applied in the field by players and coaches and get valid data concerning their athletic performance.

Finally, the third study of this dissertation aimed at analysing the correlation between different fitness markers and athlete's performance in the Portuguese national badminton team. The main takeaways from this study are the significant correlation between the performance in singles and doubles in both male and female players. Also, a significant correlation was found between mixed doubles performance and body water and Skeletal Muscle Mass (SMM). A negative correlation was also found between lower limb power and mixed doubles performance in female players.

The overall conclusion of this dissertation is that there is a shortage and lack of consistency in the literature regarding the assessment of fitness markers in badminton players. It would be important to establish standardized fitness tests useful for badminton players and also to publish reference values for elite players. Not only would it lead to enhance the evaluation process made by coaches and athletes, but it would also contribute to the development of the sport.

This dissertation also showed that male and female elite badminton players that play both singles and doubles events have better performance.

It seems that, for badminton players, we could not observe a beneficial specialization effect, meaning that, the best players are not specialized in either the doubles or singles event.

Furthermore, our findings may suggest a beneficial effect of diversifying the involvement in both singles and doubles competition. Future research is warranted to enlighten this issue. For female athletes who wish to improve their mixed doubles performance, it may be recommended that they emphasize their training on other markers not analysed in this study instead of focusing on increasing lower limb power. Also, elite players who seek a performance increase in the mixed doubles event, should also try to increase their skeletal muscle mass (across all segments) and their body water.

We are confident that the findings of our work will help coaches in the process of assessing and managing badminton players fitness levels. Further studies may help to establish more robust knowledge regarding the most important markers for performance and related cut-off values.

Keywords: Badminton, Fitness, Sports Performance, High-level athletes, Standardized fitness testing.

Resumo da Tese

A presente tese inclui três estudos originais centrados na avaliação das componentes da condição física e a sua relação com o rendimento desportivo no badminton.

O primeiro estudo trata-se de uma revisão de escopo e teve como âmbito sumariar e analisar a literatura atual relativamente a que testes são utilizados predominantemente para avaliar cada um dos diferentes marcadores da condição física (agilidade, equilíbrio, composição corporal, resistência cardiovascular, coordenação, flexibilidade, resistência muscular, potência / força explosiva, tempo de reação, velocidade e força) em atletas de badminton. A avaliação dos marcadores da condição física ainda é inconsistente e muito diversa. Isto dificulta o processo de comparação de resultados e a extração de conclusões válidas. Trabalhar na padronização dos testes de condição física em atletas de badminton permitirá uma melhoria do desporto e serviria de base para que investigações mais profundas e significativas sejam elaboradas no futuro.

O segundo estudo visou realizar uma avaliação e caracterização do atleta português de badminton em relação a quatro marcadores da condição física (agilidade, composição corporal, potência / força explosiva e resistência cardiovascular), bem como dados sociais, e comparar estes resultados com a literatura atual existente. A publicação de valores de referência para jogadores de elite de badminton portugueses pretende aumentar a literatura disponível e pode contribuir para uma abordagem de treino mais científica, enquanto fornece ferramentas acessíveis que podem ser aplicadas em campo por atletas e treinadores, e obter dados válidos sobre o seu rendimento desportivo.

Por fim, o terceiro estudo desta tese tem como objetivo analisar a correlação entre diferentes marcadores da condição física e o rendimento desportivo dos atletas da seleção nacional portuguesa de badminton. Os resultados encontrados no presente trabalho permitem concluir que apenas alguns marcadores da condição física apresentaram algum nível de consistência nas ferramentas de avaliação utilizadas, enquanto a grande maioria carecia de consistência e robustez. As principais conclusões deste estudo são a correlação significativa entre o desempenho em singulares e pares em atletas masculinos e femininos. Além disso, foi encontrada uma correlação significativa entre o desempenho em pares mistos, água corporal e massa muscular esquelética. Também foi encontrada uma correlação negativa entre potência de membros inferiores e desempenho em pares mistos em atletas do sexo feminino.

A conclusão geral desta dissertação é que existe uma escassez e falta de consistência na literatura no que diz respeito à avaliação de marcadores da condição física em jogadores de badminton. Seria importante estabelecer testes físicos padronizados úteis para jogadores de badminton e também publicar valores de referência para jogadores de elite.

Não só levaria a uma melhoria do processo de avaliação por parte de treinadores e atletas, mas também contribuiria para o desenvolvimento da modalidade. Esta dissertação também mostrou que jogadores de elite masculinos e femininos de badminton que participem nas provas de singulares e pares em simultâneo, apresentam um melhor desempenho.

Parece que para jogadores de badminton, não é possível observar um efeito de especialização benéfico, ou seja, os melhores jogadores não são especializados em nenhum dos dois. Além disso, as nossas descobertas podem sugerir um efeito benéfico da diversificação do envolvimento nas competições de singulares e pares. Serão necessárias pesquisas futuras para esclarecer esta questão.

Para atletas femininas que desejam melhorar o seu desempenho na prova de pares mistos, pode ser recomendado que enfatizem o seu treino noutros marcadores não analisados neste estudo, ao invés de focar no aumento da potência dos membros inferiores. Além disso, jogadores de elite que procuram aumentar o seu desempenho na prova de pares mistos também devem tentar aumentar a sua massa muscular esquelética (em todos os segmentos) e a água corporal.

***Palavras-chave**: Badminton, Rendimento Desportivo, Atletas de Alto Nível, Condição Física, Testes Físicos Padronizados*

Index

Figures Index

Tables Index

Chapter 1 – General Introduction

1.1 Research Rationale

1.1.1 Badminton

Badminton is one of the most popular sports in the world, with around 200 million practitioners worldwide (1). It is an Olympic sport, which can be practiced individually or in pairs. It is played in a court by two or four players (singles or doubles, respectively). It is a sport played with a racket, where there is no contact and which requires jumping, changes of direction, rapid arm movements and a high level of postural control (2).

Despite being a high competition sport, it is also widely practiced in the context of leisure, having, surprisingly, such a high number of practitioners worldwide. This large number is due to mainly two factors, namely the high prevalence of the sport in Asian countries (being one of the main sports in regions such as China and Malaysia), and because it is a very easy sport to practice in public spaces such as parks and other outdoor environments, which works as an invitation to new and more practitioners of the modality. Considering its nature, and being a no contact sport that demands jumps, lunges, sudden changes of direction and explosive movements, there are many injuries in badminton, mainly in the soft tissues of the lower limbs. It is also noteworthy that the prevalence of ligament sprains and ruptures is higher in younger badminton players, while muscular injuries are more frequent in older badminton players (3).

Despite this, the practice of badminton, even if in a leisure context, is positively related to the improvement of the health and well-being of the untrained population (4).

The recreational practice of badminton is a valid strategy to combat physical inactivity and may also have benefits regarding various levels of health (physical, mental, and social). When compared to other types of physical activities and other sports, badminton generally offers more positive results in the three previously mentioned health levels. Furthermore, this health impact has been demonstrated across all types of populations, ages and genders, with benefits seen for people with various types of disabilities as well, including even visual impairment (5).

Badminton when played at a higher level requires a combination of aerobic and anaerobic systems for the energy made available and used by practitioners, and the involvement of these systems depends on the nature of the rally or point, i.e., depending on whether the point was intense and lasting or not very intense and short.

It also depends on the duration of the game, or in other words, if it was a game with a very long duration (for example a game that goes to the third set with very disputed points and with many shots in each) or a game with a shorter duration (for example, a game with only 2 sets and with not many disputed points and few shots (6).

In addition to the very demanding energy demands, Badminton also demands high levels of technical skill and mental acuity, as well as other performance requirements, which include endurance, speed, strength and agility (7).

In Portugal, badminton has shown modest growth, with 1,886 federated players from 57 affiliated clubs (8). The entity that regulates the sport at a national level is the Portuguese Badminton Federation. This entity is responsible for the organization, structuring, and regulation of sporting and competitive practice at national level. In Portugal, competitions are organized into 3 main age categories, namely, seniors or athletes aged 19 or older, being distinguished in 3 levels according to the level of play, D, C and Absolutes; non-seniors or athletes aged 18 or under, being divided into groups based on their age, namely under-19, under-17, under-15, under-13 and under-11 (all under-19 athletes may participate in senior competitions, some under-17 athletes may also participate if they meet national ranking requirements and other exceptions that will have to be evaluated by the Portuguese Badminton Federation) and veterans or athletes aged 35 or over (they can also participate in the senior categories if they so wish) (9,10).

There are several moments of competition during a sports season, namely four zonal rounds (each round consists of five tournaments played simultaneously in five different zones), four national rounds (Each round played in one location with athletes that qualified via zonal rounds or by having enough ranking points from the previous season, club tournaments or a mix of all.), four club tournaments (organized by clubs affiliated with the Portuguese Badminton Federation), final tournament called the national championship (where the national champions of each category and modality are crowned), male and female team tournaments (which will crown the national team champion for that season) and Club League, which is a competition of mixed teams played in a league format over four different dates (9). However, for the final ranking of each season, only the nine best results from among all the disputed competitions count. Within each tournament (excluding team events and club league, both which have their own regulation), the events can be organized into groups, where one or two athletes/pairs from each group are selected and proceed to a final phase of elimination, or in a system of elimination at the first loss (no groups).

Each match is played to the best of three sets, each set being played to twenty-one points. In case of a tie at twenty points, to win, an athlete must achieve a difference of two points from his opponent (for example 22-20) up to a maximum of thirty points (10). During each season (which starts in January and ends in December), each athlete that competes in zonal or national competitions present in the Portuguese Badminton Federation’s calendar will be ranked based on their performance.

Athletes are also separated based on their age in the case of veterans and non-seniors (age rankings) and based on their level of play (D,C, or Absolute) in the case of senior athletes. In the case of non-senior and senior athletes, there are two types of rankings: zonal and national. Zonal rankings are separated on six different geographic locations, namely, North, South, Centre, Lisbon, Azores, and Madeira. Each location has their own tournaments and athletes from each location are ranked based only on the 4 different zonal tournaments. As for national rankings, those will be established by the sum of the nine best scores obtained by each athlete in the National Seniors Circuit competitions (Zonal Phase, National, Club Tournaments, National Senior Team Championships and National Senior Championship) and in the competitions of the International Circuit of Seniors and Para badminton (competitions under the umbrella of Badminton Europe and Badminton World Federation) (11).

Despite being such a popular sport, it is safe to say that badminton is a sport predominantly dominated and practiced in Asian countries (112), as there is a greater investment in the sport, and it is also rooted in the culture of the population. In Portugal specifically, there is a lack of existing literature surrounding this sport and we personally consider that there is a big opportunity for growth and further development of this sport in this country.

1.1.2 Physical Fitness

Physical fitness is a set of attributes that people have or achieve. Being physically fit has been defined as the ability of your body systems to work together efficiently to allow you to be healthy and perform activities of daily living (12).

The literature has defined two approaches (two types) to physical fitness: health related fitness and skill related fitness or motor performance (13). Health-related fitness is theoretically defined as a multidimensional construct containing the markers, cardiovascular endurance, muscular strength, muscular endurance, flexibility, and body composition (14), while skill or performance related fitness is broken down into six markers, namely, agility, coordination, balance, power, reaction time, and speed (15). For the purposes of this dissertation, the designation “physical fitness” will have a global approach, integrating both the markers of fitness related to health and skill and will be used to refer to any topic pertaining to physical fitness.

Physical fitness markers have been shown to have a significant relationship with enhanced outcomes in physical activity, including sports performance (16). In other words, an athlete’s physical fitness is very important for their sports performance. Beyond specific skill training, physical fitness is a key component in determining and predicting the success of a badminton player (17,18). Thus, for improving the performance of badminton players, it is important to identify the specific traits and parameters, which contribute to the improvement of one’s abilities (19). With this in mind, a badminton player looking to excel in the sport should seek to improve in each individual fitness marker as they all are an important part of the sport.

Agility is defined as a rapid whole-body movement with a change of velocity or direction in response to a stimulus. It is also a fundamental variable for excellent performance in badminton (20). Agility is needed in order to maintain balance when performing manoeuvres rapidly and accurately. In the context of the sport, agility is associated with the capability that an athlete has to move around the court and changing directions, while maintaining balance and doing so as fast as possible (21).

Body composition is a factor that can influence athletic performance and as such is of considerable interest to athletes and coaches (22). The evaluation of anthropometric measurements is widely used for various purposes, such as identifying talent (23) and monitoring the development of muscle mass, which can contribute to improving body movement and metabolic demand (24). It becomes, therefore, crucial for athletes and coaches to try to understand which body composition parameters should be optimized to ensure the best performance of athletes. Due to the nature of the sport, badminton requires that athletes are able to lift their bodyweight repeatedly against gravity and put load on their joints constantly (25).

This in terms, means that a badminton player's body composition will have an impact on their performance on the court.

Balance refers to an individual's ability to maintain their line of gravity within their base of support (26). In badminton, irrespective of the strokes they want to play, the athletes need to maintain their centre of gravity within the base of support, in order not to lose balance and to move in any direction after returning the shuttlecock (27), therefore balance is a crucial aspect of the sport.

Cardiovascular endurance is the ability of the lungs, heart, and blood vessels to deliver a certain amount of oxygen and nutrients to cells to meet the needs of physical activity that lasts a long time (28). In badminton, this translates to the ability to continue a rally for a long period of time without fatiguing rapidly. It is a fundamental skill in any sport and badminton is no exception.

Coordination may be defined as the ability to use different parts of the body together smoothly and efficiently (29). In badminton, the athletes need to perform and switch between strokes in a brief time frame while depending on balance, agility, and ball handling skills (30). By improving their coordination, athletes will be able to move more efficiently on court and perfect their technical skills.

Just like all markers of physical fitness, flexibility is also a very important in most sports. In badminton there is a correlation between higher levels of flexibility and sports specific performance (31).

Muscular endurance is the ability of a muscle or group of muscles to perform repetitive contractions against a force for an extended period of time (13). This marker has an indirect influence in badminton because the athlete must be able to maintain, throughout the entirety of the match or competition, the movement of hitting the shuttlecock and moving around the court, which requires many repetitions of force production (32).

Due to the highly fast nature of badminton, athletes are forced to constantly analyse and adapt during the match. This forces the player to react precisely and quickly thus improving their judgment and anticipation skills (33). This, in terms, means that faster reaction times will lead to better performance for badminton players (34).

One of the most frequent advice given by badminton coaches to athletes is to reach the shuttle at its highest point. If a player lacks speed, he will struggle to perform this task. Not only will a faster player be able to move around the court quicker, but he will also reach shots quicker, putting pressure on his opponent.

Strength and power are essential for badminton players. Lower-limb strength and upper-limb power has been showed to correlate to better agility and speed on court in these individuals (35,36).

These findings are consistent with empirical evidence, which suggest that stronger and more powerful muscles will be able to produce higher force outputs be it in their shots, or their movement, thus improving performance.

Based on the presented evidence, physical fitness stands as an important predictor of athlete's performance. Nevertheless, there is some scarcity in the literature concerning guidelines and cutoff values regarding badminton players.

This lack of existing recommendations directed towards these athletes is a knowledge gap that may limit coaching and athlete development in this sport. For this reason, the authors aimed at addressing this knowledge gap by means of a scoping review. Subsequently a characterization study, and finally a cross-sectional study based on the data collected from the review. The current dissertation is composed of five chapters each outlined and described in section 1.4 of this document.

1.2 Research Questions

Since there is some scarcity in the available literature regarding the assessment of fitness markers and their relationship with badminton sports performance, it was identified the need to contribute to the understanding of the importance of fitness testing in badminton players and increase the available information regarding this topic. In order to do so, the following questions were formulated:

1- What are the tests predominantly used in the assessment of badminton players and what tests are considered the gold standard?

2- How is the Portuguese elite badminton player characterized in regard to four different physical fitness markers (agility, body composition, cardiovascular endurance, and power)?

3- Which studied fitness marker is most correlated with badminton sports performance in elite Portuguese elite badminton player?

1.3 Purposes of this research

The main purpose of this dissertation was to contribute towards the development of the research in Portugal in regard to badminton, as well as to increase the available information concerning the assessment of fitness markers and the relationship between different fitness markers and badminton sports performance. With this in mind, the following specific purposes of this dissertation were formulated:

1- To analyse the state of the art regarding which tests are predominantly used to assess each of the different fitness markers (agility, balance, body composition, cardiovascular endurance, coordination, flexibility, muscular endurance, power, reaction time, speed, and strength) in badminton players;

2- To characterize the Portuguese elite badminton player in regard to four markers of fitness (agility, body composition, power, and cardiovascular endurance);

3- To analyse the relationship between different fitness markers and sports performance of elite Portuguese badminton players.

1.4 Outline of this dissertation

The present dissertation is composed of five chapters, as presented subsequently.

Chapter 1 – Introduction

The introduction chapter of this dissertation exhibits the rationale for the present research. It introduces the studied problem as well as the purposes of the dissertation and the general research questions.

Chapter 2 – Study 1: "Fitness Tests for The Assessment of Badminton Players – A Scoping Review."

This chapter presents study 1. The aim of this study was to provide an analysis and summarize the existing literature, regarding which tests are predominantly used to assess each of eleven different fitness markers (agility, balance, body composition, cardiovascular endurance, coordination, flexibility, muscular endurance, power, reaction time, speed, and strength) in badminton players.

Chapter 3 – Study 2: "Characterization of Portuguese National Team Badminton Players Key Fitness Markers."

This chapter presents study 2. The aim of this study was to characterize the Portuguese elite badminton player in four fitness markers (agility, body composition, power, and cardiovascular endurance) as well as biosocial data, and to compare the values obtained with data from recent existing literature.

Chapter 4 – Study 3: "Usefulness of Key Fitness Markers for the Prediction of Portuguese National Team Badminton Players Performance and Ranking."

This chapter presents study 3. The aim of this study was to analyse the relationship between various fitness markers (agility, body composition, power, and cardiovascular

Chapter 5 – Conclusions

This chapter presents the main and final conclusions of this dissertation, those directly from the results, and their practical implications for badminton coaches in the field and also finding gaps and opportunities for further research.

References

This chapter presents all the references cited in this dissertation, ordered by appearance in the entire document. In the present dissertation, all references are cited and numbered according to the Vancouver normative.

Annexes

This chapter presents all annexes that pertain to the current dissertation, ordered by appearance in the entire document. It includes tables, figures and all other documents that in some ways were needed during the elaboration of this dissertation.

Chapter 2 – Study 1: Fitness Tests for The Assessment of Badminton Players – A Scoping Review.”

Abstract

Physical fitness is directly associated with sports performance. Considering the specificity of badminton, in order to improve performance, it is important to use sport-specific approaches. To our knowledge, some shortage of literature exists surrounding specific fitness assessment tools recommended for badminton players. This may undermine the work of coaches and the performance of athletes. **PURPOSE**: The aim of this study was to perform a scoping review in order to summarize and analyse the tests used to assess physical fitness in badminton players. **METHODS**: This study followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) guidelines. Databases including EBSCO, PubMed, and Web of Sciences, were searched for published data up to march, 16th, 2023, regarding each of eleven physical fitness markers. Two independent authors screened the articles, using the Rayyan software. **RESULTS**: Twenty-six studies were eligible to be included in this scoping review (n=12 agility; n=6 balance; n=20 body composition; n=7 cardiovascular endurance; n=1 coordination; n=1 muscular endurance; n=1 flexibility; n=8 power; n=3 reaction time; n=7 speed; n=11 strength). The authors found a wide variety of tests used in the assessment of badminton players and a consensual gold standard could not be determined for each fitness marker. Only the assessment of body composition, speed and strength presented some consistency in the assessment tools, namely the use of weight and height, the 30m sprint test and the handgrip dynamometer test, respectively. Nevertheless, these tests may be considered generic and not sport-specific for badminton. All other fitness markers lack consistency in the physical fitness assessment tools reported in the literature. **CONCLUSION**: Based on the results of this scoping review, we can conclude that the assessment of fitness markers in badminton players is not yet fully established, nor consistent, and needs further research for the development or confirmation of physical fitness assessment tools that are useful for badminton coaches and athletes’ performance.

2.1 Introduction

Physical fitness refers to the ability of the various body systems to work together efficiently to perform daily activities and stay healthy and is typically measured using six skill-related markers (agility, balance, coordination, power, reaction time, and speed) and five health-related (body composition, cardiovascular fitness, flexibility, muscular endurance, and strength) (37). Thus, the relationship between physical fitness and sports performance becomes clear because the latter is based in a complex and intricate diversity of variables, which include physical (general & specific conditions), psychological (personality & motivation), sociological and physical (body morphology, anthropometry & body composition) characteristics (38). Regarding sports, we know that the quality of the training can be improved, above all, by using special technique-specific exercises and sport-specific tests (39). Consequently, it is important to direct one's attention to the development of highly specific means of training. With badminton being a very performance-oriented sport by nature and being characterized by very precise high-intensity, intermittent actions, it becomes important to identify the specific traits and markers, which contribute to the improvement of performance. In Portugal there is very few data available regarding physical fitness and badminton, but international data tells us that there is a big correlation between physical fitness and performance in badminton players (40). Taking this into consideration, it is crucial for badminton coaches and elite athletes to know how to test and train these markers to improve performance.

There is a scarcity of descriptive data on the performance capabilities of badminton players (41), but despite this, it has also been established that apart from the demands of high levels of technical skill and mental acuity, essential requirements for badminton fitness include stamina, speed, endurance, strength, and physical agility, alongside other physical fitness markers (7). Because of the lack of descriptive data regarding physical fitness and performance in badminton, this key component often is neglected by athletes and coaches, who focus primarily on skill training. But we know that if a player intends to achieve reasonable success in international badminton competitions, improvements in physical fitness need to be emphasised in addition to skills training.

For that purpose, it becomes imperative that coaches know not only the best way to train each physical fitness marker in the most adequate way but also know how to test and evaluate each fitness marker. In the meantime, there is a huge diversity of tests that can be applied to measure each physical fitness marker.

This proves to be a problem because the lack of existing literature in this regard makes it difficult to standardize and uniformize the testing for each fitness marker in badminton players.

Standardizing fitness testing in any sport is beneficial to athletes and coaches because it allows them not only to compare results to normative data (42), but also to establish the strengths and weaknesses of the athletes (43), monitor their progress (43), predict performance, and helps with the identification of talents (44) as well as many other documented benefits (45). Due to this big diversity of existing tests, some of these benefits may be lost and coaches may find more difficult to know what aspects of their athlete's physical fitness may need work and how does their performance compare to other elite athletes. This lack of specificity regarding what are the most adequate tests to measure physical fitness markers in badminton may have a detrimental effect on the work done by coaches with badminton players because it will be harder to tailor their training programs according to their specific needs. By conducting a study with standardized fitness tests, coaches and athletes can effectively monitor improvements in the fitness markers they find more important to improve their own specific performance. This data can be used to make targeted adjustments to their training regimen to improve their performance in specific areas, thus enhancing their performance on the court.

Therefore, given the current limitations of existing meta-analyses and syntheses, and the need to contribute to the assessment and standardization of fitness testing in badminton, the purpose of this study is to analyse and summarize the existing literature, regarding what tests are predominantly used to assess each of the eleven different fitness markers (agility, balance, body composition, cardiovascular endurance, coordination, flexibility, muscular endurance, power, reaction time, speed, and strength) in badminton players.

2.2 Methods

For this scoping review, we adopted the PRISMA-ScR guidelines (46). This review was also done using Rayyan (47). Contrary to a systematic review, a scoping review aims to provide an extensive coverage of a certain topic while a systematic review does an exhaustive coverage of a certain topic and assesses the research quality of each article included. As such, the quality assessment of each article was not conducted because it is not mandated by the PRISMA guidelines for scoping reviews (46).

2.2.1 Eligibility Criteria

Studies were considered eligible and included in the review if they met the following criteria:

1- The study includes male and female competitive badminton players with more than 16 years old;

2- The study includes at least measurements of one or more outcomes of interest (Agility; Balance; Body Composition; Cardiovascular Endurance; Coordination; Endurance; Flexibility; Power; Reaction Time; Speed; Strength);

3- The study must include participants who are body abled;

4- The study must include only papers written in English.

2.2.2 Information Sources

To select studies for our research, we searched three different electronic databases (EBSCO, PubMed, and Web of Science) from inception up to March 16, 2023. For each fitness component, we utilized different command lines during the electronic searches. The search syntax was initially developed for PubMed (Table 1) and then adapted for use in the other databases. All search results were then extracted to a reference manager (48) and split in different folders regarding what fitness marker they analysed.

Table 1. Search Syntax originally designed for PubMed and then adapted to other databases.

Fitness Component	**Keywords Used**
Agility	Agility AND Badminton AND Assessment
Balance	Balance AND Badminton AND Assessment
Body Composition	(Body Composition OR Body Fat OR Muscle Mass OR Fat Mass) AND Badminton AND Assessment
Cardiovascular Endurance	(Cardio Endurance OR Cardiovascular Endurance) AND Badminton AND Assessment
Coordination	Coordination AND Badminton AND Assessment
Muscular Endurance	(Muscular Endurance OR Resistance) AND Badminton AND Assessment
Flexibility	(Flexibility OR Range of Motion) AND Badminton AND Assessment
Power	Power AND Badminton AND Assessment
Reaction Time	Reaction Time AND Badminton AND Assessment
Speed	Speed AND Badminton AND Assessment
Strength	(Muscular Resistance OR Strength) AND Badminton AND Assessment

2.2.3 Selection Process

After extracting all the references to the reference manager, all papers were uploaded to Rayyan (47). Rayyan is a software which enables researchers to organize, manage and accelerate their collaborative literature reviews (47). When all articles were uploaded to the software, all duplicates were then excluded.

We then proceeded to screening all the abstracts. Two review authors (the main researcher and other researcher of the project) screened and reviewed all titles and abstracts independently to see if the studies were eligible based on the inclusion criteria. The previously mentioned review authors then retrieved and assessed independently the full texts of the potential eligible studies.

Any inconsistency in the results was solved by group discussion involving a third author (the main adviser) who would make the final decision by consensus. In total, twenty-six studies were included in the qualitative synthesis.

2.3 Results

This scoping review included six hundred and thirty-nine articles that were identified in the initial search. After the exclusion of duplicates process, three hundred and forty-eight articles remained. These articles were then screened by abstract, and thirty-five articles remained. Finally, after the full article screening, twenty-six studies were ultimately included in this study (23,41,49–72). Included Sources of evidence are synthesized in Figure 1.

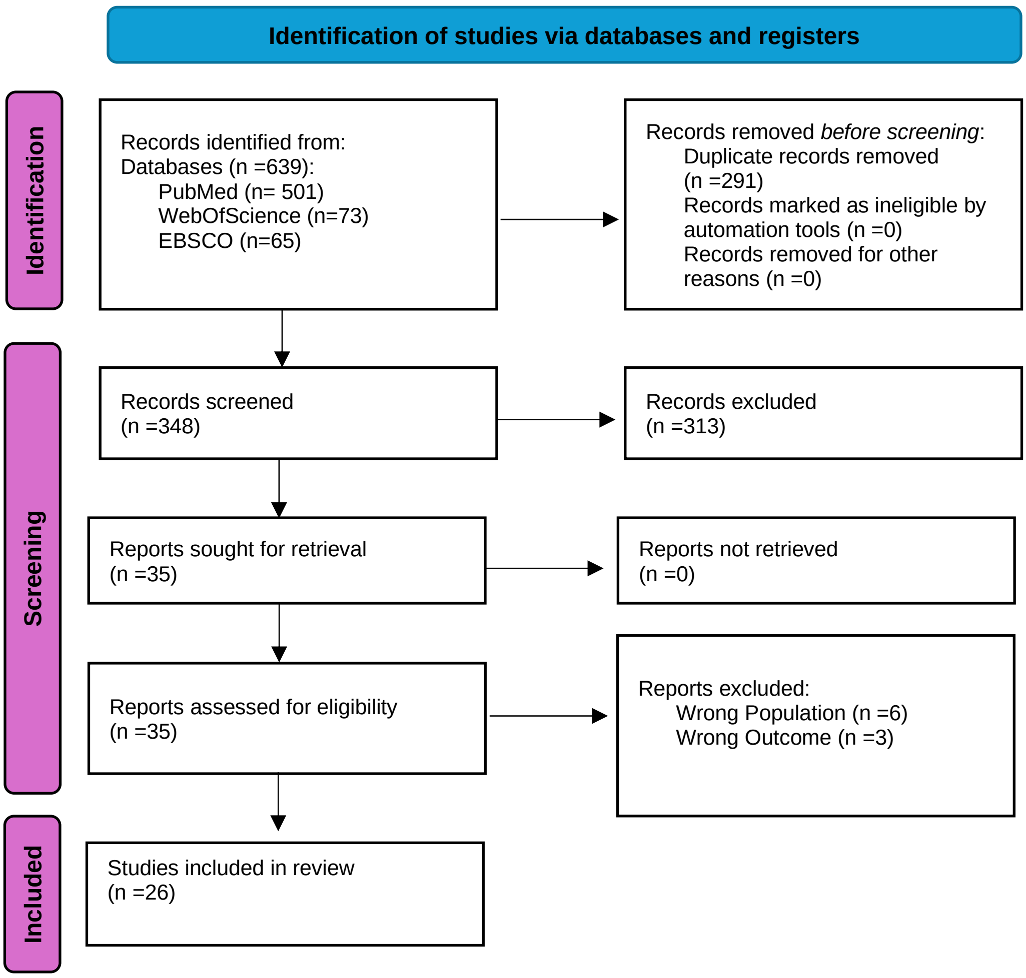

Figure 1. Flow chart of literature search strategy and screening of the identified research for inclusion.

Eleven different tables were created, each table regarding one component of the physical fitness. In each table, the publication's goal, sample size, instruments used, cutoff values, intervention and measuring protocol were described. All eleven tables are presents in the annexes section of this dissertation (Annexes 1-11).

In general, most of the publications included in this study were Cross-Sectional studies. Out of the 26 included papers, twelve (23,41,51,53,59,63,65–67,70–72) were cross-sectional type studies, meanwhile one (53) of those was a followed cross-sectional design but it was also a validation study. The second most used study design was Randomized Controlled Trial with eight (52,54–56,61,62,64,68) papers following this design, while two (55,64) of these papers were Randomized Controlled Trials with a Crossover Design. Also, five (49,57,58,60,69) studies followed a Cohort Study design and one (50) study followed a Two-Intervention-Groups Randomized Trial study design.

2.3.1 Agility

A total of 12 (23,49–57,59,60) publications were analysed. Out of these twelve papers, three (49,57,60) followed a Cohort study design, three (23,51,59) followed a Cross-Sectional design and 3 (52,54,56) followed a Randomized Controlled Trial design. Out of the three remaining papers, one (55) followed a Randomized Controlled Trial with a Crossover design, other (54) followed a Cross-Sectional and Validation design and other (50) followed a Two-Intervention-Groups Randomized Trial.

To measure agility, a total of seventeen tests were applied. The modified Change of Direction (COD) (51,52) Test and the Agility T-Test (49,56) were the most used, being applied in two different publications each. All the remaining tests were applied in only one study each with badminton players.

2.3.2 Balance

A total of five (52,54,60–62) publications were analysed. Out of these five studies, four (52,54,60,62) followed a Randomized Controlled Trial design while one (60) followed a Cohort design.

To measure balance, a total of five tests were applied. The Y Balance Test (YBT) (52,61) was the most used, being applied in two different publications. All the remaining tests were applied in only one study each with badminton players.

2.3.3 Body Composition

A total of twenty (23,49,51,52,54–61,63–70) publications were analysed. Out of these twenty papers, eight (23,51,59,63,65–67,70) followed a Cross-Sectional study design, while five (49,57,58,60,69) followed a Cohort design, five (52,54,56,57,61) followed a Randomized

Controlled Trial design and two (55,64) followed a Randomized Controlled Trial with a Crossover design.

To assess body composition, a total of ten parameters were measured. Height (23,49,51,52,54–62,63–67,69,70) and Body Mass (BM) (23,49,51,52,54–60,63– 67,69,70) were the most measured parameters, being assessed in eighteen different publications. Body Mass Index (BMI) (23,55–61,68,70) was measured ten times while Fat Mass (FM) (23,49,57–59,65,69) was measured seven. Fat Free Mass (FFM) (49,65,69) was assessed three times while forearm length (63,70) was assessed twice. All remaining parameters were applied in only one study each with badminton players.

2.3.4 Cardiovascular Endurance

A total of seven (23,41,55,57,59,64,69) publications were analysed. Out of these seven papers, three (23,41,59) followed a Cross-Sectional study design, while two (57,69) followed a Cohort design and two (55,64) followed a Randomized Controlled Trial with a Crossover design.

To measure cardiovascular endurance, a total of six tests were applied. The Yo-Yo Intermittent Test Level 1 (55,69) was the most used, being applied in two different publications.

It should be noted that the Maximal Oxygen Uptake (Vo^2Max) was measured three times, although with three different tests (57,59,64). All remaining tests were applied in only one study each with badminton players.

2.3.5 Coordination

Only one publication was analysed (23). This paper followed a Cross-Sectional study design. To measure coordination, only one test was applied. That was the three subtests of the *KörperkoordinationsTest für Kinder* (KTK) (23).

2.3.6 Flexibility

Only one publication was analysed (23). This paper followed a Cross-Sectional study design. To measure flexibility, two tests were applied. Those were the Sit-And-Reach Test (EUROFIT) and the Shoulder Rotation Test (23).

2.3.7 Muscular Endurance

Only one publication was analysed (23). This paper followed a Cross-Sectional study design. To measure muscular endurance, two tests were applied. Those were the Knee Push-ups and Sit Ups Tests according to the *BruininksOseretzky* Test (BOT-2) of Motor Proficiency procedures (23).

2.3.8 Power

A total of eight publications were analysed (23,51,55–58,60,66). Out of these eight papers, three (23,51,66) followed a Cross-Sectional study design, three (57,58,60) followed a Cohort design, one

(56) followed a Randomized Controlled Trial design and one (55) followed a Randomized Controlled Trial with a Crossover design.

To measure power, a total of nine tests were applied. The Countermovement Jump (CMJ) Test (23,51,57,58,66) was the most used, being applied in five different publications. The Vertical Jump (VJ) Test (55,60) and the Standing Broad Jump (SBJ) Test (23,56) were applied in two different publications while all remaining tests were applied in only one study each with badminton players.

2.3.9 Reaction Time

A total of three publications were analysed (64,68,71). Out of these publications, one (64) followed a Randomized Controlled Trial with a Crossover study design, one (68) followed a Randomized Controlled Trial design and one (71) followed a Cross-Sectional design.

To measure reaction time, a total of three tests were applied. All three tests were only applied in one study each with badminton players.

2.3.10 Speed

A total of six publications were analysed (23,51,55,56,60,67). Out of these six publications, three (23,51,67) followed a Cross-Sectional study design, one (55) followed a Randomized Controlled Trial with a Crossover design, one (56) followed a Randomized Controlled Trial design, and one (60) followed a Cohort design.

To measure speed, a total of five tests were applied. The 30-meter sprint test (56,60,67) was the most used, being applied in three different publications and being applied in another study but with a variant (2x30m Sprint Test) (23). All remaining tests were applied in only one study each with badminton players.

2.3.11 Strength

A total of eleven publications were analysed (49,52,55,58,63,65,66,68–70,72). Out of these eleven publications, five (63,65,66,70,72) followed a Cross-Sectional study design, while three (49,58,69) followed a Cohort design, two (52,68) followed a Randomized Controlled Trial and one (55) followed a Randomized Controlled Trial with a Crossover. To measure strength, a total of ten tests were applied. The Handgrip Dynamometer Test (55,58,69) was the most used, being applied in three different publications. All remaining tests were applied in one study each with badminton players.

2.4 Discussion

The aim of this scoping review was to summarize, analyse and offer a synthesis of the current existing research regarding the panorama of the assessment of physical fitness in badminton players. In this section, we present a brief overview of the main results included in this study, with a focus on each marker of physical fitness.

2.4.1 Agility

In regard to agility, some tests were used but there is no consensus regarding which test can be viewed as the “gold standard” to accessing agility. The most used tests were only used twice each while the vast majority of tests were only applied once, meaning that there is a big lack of consensus in the literature, and it can be difficult to extrapolate meaningful conclusions from it.

If an author were to pick a test to apply on their own research, some factors should be taken into consideration, namely, what type of materials are available for them to use, the simplicity or complexity of the test and what test seems to adapt better to the author’s target population and investigation purposes.

2.4.2 Balance

In consideration to balance, only five tests were used and while the YBT (52,61), appears to be the most used test, the sample size of this study is not enough to draw meaningful conclusions. That being said, if an author were to pick a test to apply on their own research, some factors should be taken into consideration, namely, what type of materials are available for them to use, the simplicity or complexity of the test and what test seems to adapt better to the author’s target population and investigation purposes.

2.4.3 Body Composition

Regarding body composition, this marker seems to be where there is more information available in the literature as well as a consensus on what parameters of body composition seem to be viewed as the most important and more meaningful to badminton. Research tends to appoint height and BM as the most used way to evaluate body composition. Meanwhile other parameters such as BMI and FM appear to also have enough data accessible do draw valid conclusions and may be viewed as viable options in regard to accessing body composition. A combination of the aforementioned markers may be considered ideal to withdraw the most amount of information from this marker.

2.4.4 Cardiovascular Endurance

In consideration of cardiovascular endurance, seven tests were conducted but there is no consensus regarding which test can be viewed as the “gold standard” to accessing cardiovascular endurance. The most used tests were only used two times each while most tests were only applied once, meaning that there is a big lack of consensus in the literature, and it can be difficult to extrapolate meaningful conclusions from it.

While conducting future research, some factors should be taken into consideration, namely, what are the materials available for use, what is the degree of complexity of the considered tests and which of those tests seem to fit in better with the research’s target population and purposes.

Other than that, measuring Vo^{2}Max appears to be a good starting point to access cardiovascular endurance, because it is widely used for athletes and the general public as a measure of aerobic fitness (73), although further research should be conducted in badminton players to withdraw conclusions for this population.

2.4.5 Coordination

In regard to coordination, there is a shortage of literature found in this line of research, with only one study being included. This in terms means that only one test was conducted, meaning therefore, that few or no conclusions can be extrapolated from it. If an author was to conduct a study on this topic with this population, it may be suggested that he uses the only test available in this research, the three Subtests of the KTK (23), while always keeping in mind that further research should be conducted.

2.4.6 Flexibility

Concerning flexibility, there is an absence of literature found in this research line, with only one study being included. This means that only two tests were applied, meaning therefore, that few or no conclusions can be extrapolated from it. If an author was to conduct a study on this topic with this population, it may be suggested that he uses one of the two tests available in this research, the Sit-And-Reach Test (EUROFIT) and/or the Shoulder Rotation Test (23). The choice regarding what test to use could be based on some factors such as the simplicity or complexity of the test and what test seems to adapt better to the target population and research purposes. It should also be kept in mind that further research should be conducted.

2.4.7 Muscular Endurance

Regarding muscular endurance, there is a shortage of literature in this line of research, with only one study being included.

This implies that only two tests were conducted, meaning, that few or no conclusions can be extrapolated from it. If a study on this topic with this population was to be conducted, it may be suggested that he uses one of the two tests available in this research, the Knee Push-ups and/or the Sit Ups Tests according to the BOT-2 of Motor Proficiency procedures (23).

The choice regarding what test to use could be based on some criteria such as the degree of complexity of the test, what materials are available and what test appears to be more coherent with the target population and investigation purposes. It should also be kept in mind that further research should be conducted.

2.4.8 Power

In consideration of power, some tests were used and there appears to be some consensus regarding which test is considered the “gold standard” to accessing power. The research tends to appoint the CMJ to be the most used test to measure this marker in badminton players. Previous literature also found that jumping and landing movements are fundamental features of many sporting activities (74), such as badminton which requires great explosive athleticism with athletes required to jump for height or distance

(2). This may also mean that tests that require jumping, like the CMJ test, are adequate to use with badminton players.

2.4.9 Reaction Time

In regard to reaction time, there is a shortage of literature found in this line of research, with only three studies being included. Also, there is no consensus regarding which test can be viewed as the “gold standard” to accessing reaction time because all tests were only used once. The combination of the small sample size and the lack of consensus in the literature makes it difficult to draw meaningful conclusions. Considering the previous data, when picking a test to use with badminton players, some factors should be taken into consideration, namely, what sort of materials are available for use, the simplicity or complexity of the test and what test seems to adapt better to the target population and to the purposes.

2.4.10 Speed

Concerning speed, six tests were used and there appears to be some consensus regarding which test is considered the “gold standard” to accessing speed. The research tends to appoint the 30-meter sprint test (56,60,67) to be the most used test to measure this marker in badminton players. While this test was the most used in this research, previous literature remarks that although sprint tests may be used for a general determination of the athlete’s explosive exercise capacity (75,76) but the transfer ability from such tests to badminton or other racket sports is questionable due to the highly specialized nature of the movement patterns that depict these sports (77–79) It might be beneficial to keep this in mind for future research and consider the adequacy of these types of tests.

2.4.11 Strength

Regarding strength, a good volume of literature was found in this line of research, in the meantime, a vast number of tests was used and there appears to be a minor consensus regarding what test is considered the “gold standard” to accessing strength. The handgrip dynamometer test was used three different times (55,58,69) while all the other tests were used only once. Despite this difference, there is a visible diversity in the tests used to measure strength. This may make it harder to draw valid conclusions. Even still, based on this study, if an author was to conduct a study on this topic with this population, it may be suggested that he uses the handgrip dynamometer test to assess strength. Previous literature also suggests that the wrist action in badminton is crucial for creating powerful shots and enhancing control over the shuttle's course (79). This may mean that a test like the handgrip dynamometer test, may give some insight in regard to a player's performance and can be adequate to use with badminton players.

2.4.12. Strengths and Limitations

The findings of the present review should be interpreted with caution and considered in light of the following limitations. Firstly, there is a visible diversity in the tests utilized to measure each marker of physical fitness. In some markers such as coordination, flexibility, and muscular endurance, only one publication was found, which in terms meant that only one test per marker was used. Meanwhile, in all other physical fitness markers, there was a big diversity of tests utilized. This makes it difficult to compare the findings produced.

Secondly, due to the shortage of studies conducted in this line of research, it would be desirable to expand the search to include papers published in more languages (mainly Chinese and Korean). This may prove to be very useful because badminton is a very popular sport worldwide and there is a high likelihood that more useful research has been conducted mainly in Asian Countries.

Finally, in some markers there is some literature available, while in others, very few is accessible. This lack of consistency and coherence may limit the development of the sport. A greater number of studies are needed specially in some markers such as flexibility, coordination, reaction time and muscular endurance. This lack of research in the aforementioned markers makes it difficult to draw reliable conclusions.

2.5. Conclusions

This scoping review provided a key insight into the state of the present literature regarding the assessment of fitness in badminton players. Our research suggests that out of the eleven analysed fitness markers, agility, balance, cardiovascular endurance, coordination, flexibility, muscular endurance, and reaction time did not appear to have a consistent test which could be viewed as the "Gold Standard for its assessment. In regard to body composition, it appears that this is the most researched marker and height, and BM were the most tested parameters to assess this marker. In consideration of power, the CMJ Test seems to be the most standardized way to assess this marker. Regarding speed, the 30m sprint test seems to be the most standardized way to assess this marker. Finally, in regard to strength, there appears to exist a minor consensus that regards the Handgrip dynamometer test as the most predominant way to assess strength.

In general, there is a scarcity of literature surrounding this topic. This is especially apparent in some markers such as coordination, flexibility, and muscular endurance. Alongside this absence of literature available, there is also a noticeable variety in the tests utilized. A lack of test standardization was also present in some of the studied fitness markers. These limitations not only make the process of comparing and drawing meaningful conclusions from the present research very challenging due to the lack of consistency, coherence, and consensus, but also may have practical repercussions as it may harm the quality of the work done by coaches and athletes towards improving their performance.

The authors consider that standardizing fitness testing would provide many benefits to the improvement of the sport and a starting point for more profound investigations to be carried over.

Given the research gaps found in this line of investigation, it becomes fundamental that further scientific production in this area is conducted. It is also important to note that the lack of consensus in the literature relative to what tests are viewed as the "Gold Standard" in each marker may condition the work done by coaches and athletes towards improving performance in each of those same markers.

Chapter 3 – Study 2: "Characterization of Portuguese National Team Badminton Players Key Fitness Markers"

Abstract

Physical fitness is directly associated with sports performance. It is important to have cutoff values of elite athletes in order to have a measure of comparison and a point of reference to where coaches and athletes can know in what aspects should they focus more or less time of training on. To our knowledge, such cutoff values don't exist in Portuguese elite badminton players. This may be hindering the development and performance of athletes and may also undermine the work of coaches. **PURPOSE:** The aim of this study was to characterize the Portuguese elite badminton player in respect to four different fitness markers and to compare the findings with other available literature. **METHODS:** Elite level Portuguese male and female badminton players (n=23) with an average age of 21.2 ± 3.5 and 23.4 ± 2.9 years old, respectively, were tested in four different fitness markers (agility, body composition, power, and cardiovascular endurance). The assessments were made over four days in a Portuguese National Badminton Team internship. One Sample t-test was used to compare results with other European data. **RESULTS:** Portuguese elite badminton players on average train less than Spanish elite badminton players. On average, Portuguese elite male badminton players are younger than the top 100 players in the world. Portuguese female elite badminton players are, on average, the same height as Polish and Spanish female elite badminton players but are also heavier. Portuguese elite male badminton players have on average, lower body fat levels than Turkish elite male badminton players, and similar levels to Spanish elite male badminton players. On average, male elite Portuguese badminton players showed better performance on the agility test when compared to Polish elite male badminton players. **CONCLUSION:** This study publishes physical fitness reference values for Portuguese elite badminton players. Both the methodology used, and the reference values may be useful for the work of coaches and athletes in achieving higher performances.

3.1 Introduction

Badminton is a sport that involves various high intensity movements, including accelerations, decelerations, quick court movements, and rapid changes of direction over short distances, all of which involve the whole body to produce maximum power. Badminton is a sport that is very physically demanding, requiring athletes to reach great levels of physical fitness. (87,88). It also includes high levels of mental acuity and technical skill (7). This is consistent with more literature that suggests that the most important characteristics of athletes in badminton are technical skill, physical performance capacity and anthropometrical factors (40). Badminton is a popular sport worldwide, but it is played mainly in Asian countries, where more investment in the sport exists, and it is also culturally deeper rooted.

There are numerous performance factors in badminton, revealing the sport's high degree of complexity. Even though, the literature suggests that the most important characteristics of athletes in badminton are technical skill, physical fitness and anthropometrical factors (40), there seems to be a lack of descriptive data regarding physical fitness and performance in badminton. These components are many times sub valued by athletes and coaches, who focus primarily on skill training (89). As time passes and technological advances become more accessible, performance analysis has become an important part of an athlete's development and coaching process and is even considered by some to provide a considerable competitive advantage (90). Unfortunately, even though performance analysis keeps evolving at a very fast rate and that coaches and athletes should strive to keep up with this advancement (91), there is still a gap in the literature regarding one of the most basic components of performance analysis, namely, physical fitness testing for badminton players.

With physical fitness being an important variable of sports performance, it becomes primordial that coaches and elite athletes have access to raw data and respective reference values on badminton specific physical fitness testing.

Taking the previous rational into consideration, a valid question to ask would be: "What physical fitness traits do elite badminton players possess?" Despite the pertinency of this question, when analysing the available literature, we quickly discover that most of the available data pertaining to performance and badminton is more focused on match analysis and the biomechanics of certain movements and strokes specific to the sport. The research involving the testing of physical fitness markers and badminton performance is somewhat scarce and as such few valid conclusions could be drawn.

Based on this, the research is scattered and there is a lack of standardized fitness testing each fitness marker in badminton players, whose fitness requirements are quite specific (92). This in terms means that it may be difficult to create a profile of the elite badminton player due to the lack of standardized testing and respective reference values. In Portugal the literature is almost non-existing regarding physical fitness and badminton, but international research tells us that there is a big connection between these two variables (93).

Consequently, given the present limitations in the literature, and the need to further contribute to the development of the research regarding physical fitness in badminton, the aim of this study is to characterize the Portuguese elite badminton player (grouped into singles and doubles) in respect to four markers of fitness (agility, body composition, power, and cardiovascular endurance) as well as biosocial data, and to compare the values obtained with data from the current existing literature.

3.2 Methods

This study deserved the approval of the Ethics Committee of the Santarém Polytechnic University under the code Nº2-2024ESDRM.

3.2.1 Study Design

This study followed a cross-sectional design. This intervention took place in the High-Performance Centre of Badminton in Caldas da Rainha, Portugal over the span of four days. In this internship, the participants were split into two different groups: Group 1 – Singles; Group 2 – Doubles. Thirteen athletes were a part of the singles group while ten athletes were a part of the doubles group. The singles group partook in the intervention on day 1 and day 2 while the doubles group partook in the intervention on days 3 and 4. Although the participants were split into groups, both groups did the intervention in the exact same conditions. One week prior to the internship, each participant was given a pamphlet with detailed explanation of each procedure for the assessments. Additionally, the declaration of informed consent was signed and / or collected on the day of the pamphlet's delivery. This process is summed up in table 2.

Table 2. Overall Design of the Intervention

One Week Prior to the Internship - Delivery of informative pamphlet - Declaration of informed consent	**Internship Day 1 – Singles Group** - Warm-up /Re-Warm-Up - Power and Agility Assessment - Cardiovascular Endurance assessment	**Internship Day 3 – Doubles Group** - Warm-up /Re-Warm-Up - Power and Agility Assessment - Cardiovascular Endurance assessment
	Internship Day 2 – Singles Group - Body Composition assessment	**Internship Day 4 – Doubles Group** - Body Composition assessment

3.2.2 Statistical Analysis

Descriptive statistics are presented as mean ± sd and range, for all analysed variables.
The one sample t-test was applied in order to compare the mean of the results of the tests used to analyse different fitness markers, as well as biosocial data, found in this study with data from the available literature.
Statistical calculations were performed using the IBM SPSS Statistics version 24 (IBM Corp, Armonk, NY, USA)

3.2.3 Sample

The sample of this study is composed by 23 elite level Portuguese badminton players, federated practitioners in the sport of badminton who were split into one of two groups: Singles (n=13) and Doubles (n=10). The inclusion criteria in the sample are as follows:

(1) Included athletes should be body-abled;

(2) The athletes must be called up for the senior and under-23 national team-level internship taking place from the 12th to the 16th of February 2024;

(3) The athlete should not be found injured or impeded by any reason to fully participate in the tasks planned for the internship.

3.2.4 Instruments and Procedures

In the present study, four markers of physical fitness were assessed over the span of two days (for each group). On the first day, prior to the beginning of the tests, a small briefing took place, where each athlete was given an identification number, and all questions and doubts were clarified. Also, each group (singles and doubles – on different days) was split into one of three sub-groups. After this short briefing, the participants went to the main hall where a short warm-up took place (table 4). After the warm-up was concluded, each sub-group started each assessment according to the order that was previously established as shown in table 3.

Table 3. Order of each group's assessments.

Group 1 (Order):
1. Agility
2. Lower Limb Power
3. Upper Limb Power

Group 2 (Order):
1. Upper Limb Power
2. Agility
3. Lower Limb Power

Group 3 (Order):
1. Lower Limb Power
2. Upper Limb Power
3. Agility

After each sub-group finished their first assessment, they then moved on to the second assessment and posteriorly the third assessment. The overall rotation scheme is shown in Figure 2.

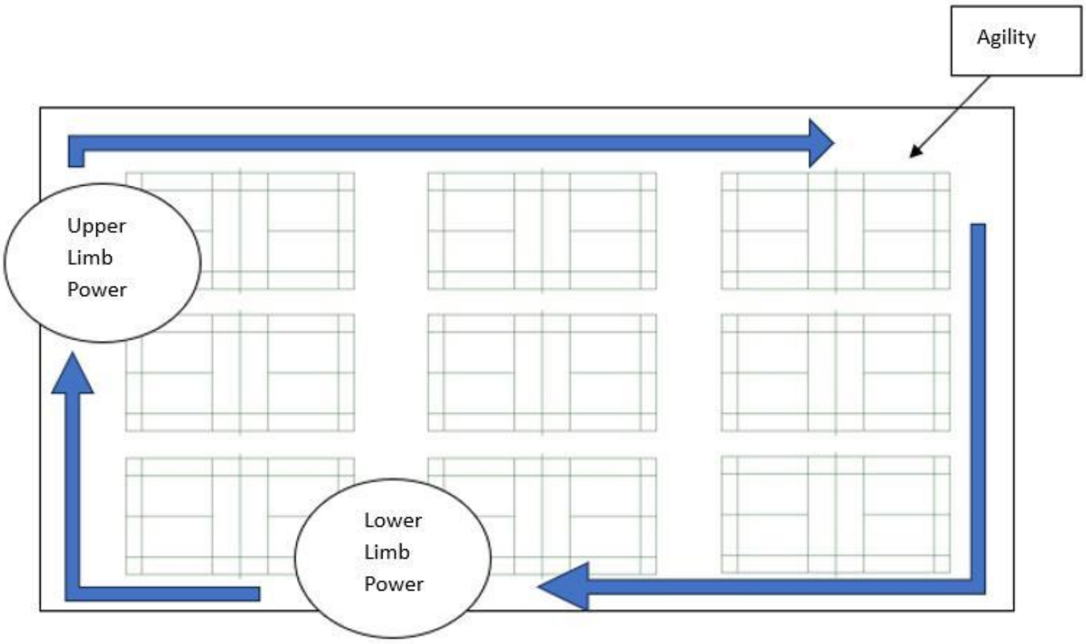

Figure 2. Rotation Scheme for the Assessment of Power and Agility.

After the Power and Agility assessments, the participants were allowed to rest for two minutes (min), after which, the Cardiovascular Endurance assessment begun. Contrary to the Power and Agility assessments, in the Cardiovascular Endurance assessment all participants performed it simultaneously and not in sub-groups. The disposition of the participants in the hall is shown in Figure 3.

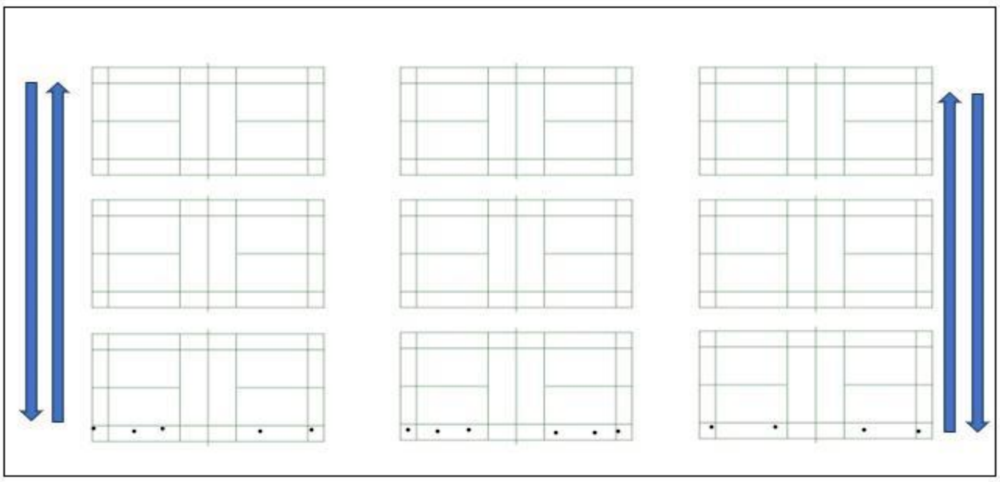

Figure 3. Graphic Representation of the disposition of the participants for the Cardiovascular Assessment.

The body composition assessment took place in the second and fourth day of the internship (for the singles and doubles group respectively) in the headquarters of the Portuguese Badminton Federation during the morning. Participants were all evaluated under the same circumstances as outlined in chapter 3.2.4.1.

All assessments occurred under the supervision of the same investigator, alongside the collaboration of the Portuguese national team coaches and physical trainer.

This same process was then repeated for the doubles group on day 3 and 4 of the internship.

3.2.4.1 Body Composition Assessment

For the body composition assessment, BM, height, and other body composition parameters (Body Fat (BF), SMM, right and left arm lean mass, right and left leg lean mass, trunk lean mass, body water, BMI and Extracellular Water to Total Body Water Ratio (ECW/TBW)) were measured. Participants were first asked to remove their shoes, any outer garments, and personal belongings prior to initiating the measurement.

BM was first measured using a digital scale (BC-543, Tanita Corp.; Tokyo, Japan) with an accuracy to 0.1 Kilogram (kg). After checking the scale is reading zero, the participant wearing light clothes stood on the centre of the scale without support and with the weight distributed evenly on both feet, the head up and eyes looking directly ahead.

After measuring BM, body height was also measured. Body height was measured using a headsquare with a retractable centimetre measuring tape (Rosscraft; Spokane, WA, USA) with the participant standing barefoot with the upper back, buttocks and heels pressed against the wall. The participant's head was positioned in the Frankfort horizontal plane, and the head plate is brought into firm contact with the vertex (94). Subjects were then asked to inhale deeply and maintain a fully erect position, while maintaining the same load on the heels. A movable headboard was then brought onto the most superior part of the head, while placing enough pressure to compress the hair of the subject. The measurement was recorded to the nearest 0,1cm. The time at which the measurement occurred should be noted (94). It is important to check if the stadiometer is checked, validated, and wiped clean before use. It is also, advisable to measure height at the same time of day if possible (95).

Finally, other body composition parameters (BF, SMM Right Arm Lean Mass, Left Arm Lean Mass, Right Leg Lean Mass, Left Leg Lean Mass, Trunk Lean Mass, Body Water, BMI, and ECW/TBW) were assessed by Bioelectrical Impedance (BI) (S10, InBody; Biospace Co. Ltd; Seoul, Republic of Korea).

Some important considerations (96) for the utilization of this device are: 1) The participant should refrain from eating for 4-5 hours before the test, exercising for 12 hours before the test; consuming caffeine (tea, coffee, and energy drinks) and alcohol 24 hours before the test and consuming diuretics within 7 days of the test. 2) No measurements were to be carried out if the participant had electrical devices such as a pacemaker or cochlear implant. 3) Shoes, socks, and tights should be removed. 4) Hands and legs should be slightly separated from the body. 5) If the skin was moist or covered with body lotion, the area should be cleaned with alcohol wipes. The participants lied down on a marquee and the electrodes were then placed on their body while they remained static.

After the analysis was completed, participants could then stand up and mark their assessment as closed.

3.2.4.2 Cardiovascular Endurance Assessment

Cardiovascular endurance was assessed with an endurance Shuttle Run (SR), also known as the "beep test" (83). This test involves continuous running between two lines 20m apart in time to recorded beeps. The participants did the test simultaneously and their test was supervised and controlled by one investigator (AP) along with the collaboration of the Portuguese national team coaches and physical trainer.

The participants stood behind one of the lines facing the other line and begin running when instructed by the recording. The speed at the start is quite slow. The subject continues running between the two lines, turning when signaled by the recorded beeps. After about one min, a sound indicates an increase in speed, and the beeps will be closer together. This continues each min (level). If the line is reached before the beep sounds, the subject must wait until the beep sounds before continuing. If the line is not reached before the beep sounds, the subject is given a warning and must continue to run to the line, then turn and try to catch up with the pace within two more beeps. The subject is given a warning the first time they fail to reach the line (within 2 meters) and eliminated after the second warning. The athlete's score is the level and number of shuttles (20m) reached before they were unable to keep up with the recording. The last level completed was recorded (Not the level where they failed at). A graphic representation of the test used is shown in figure 4.

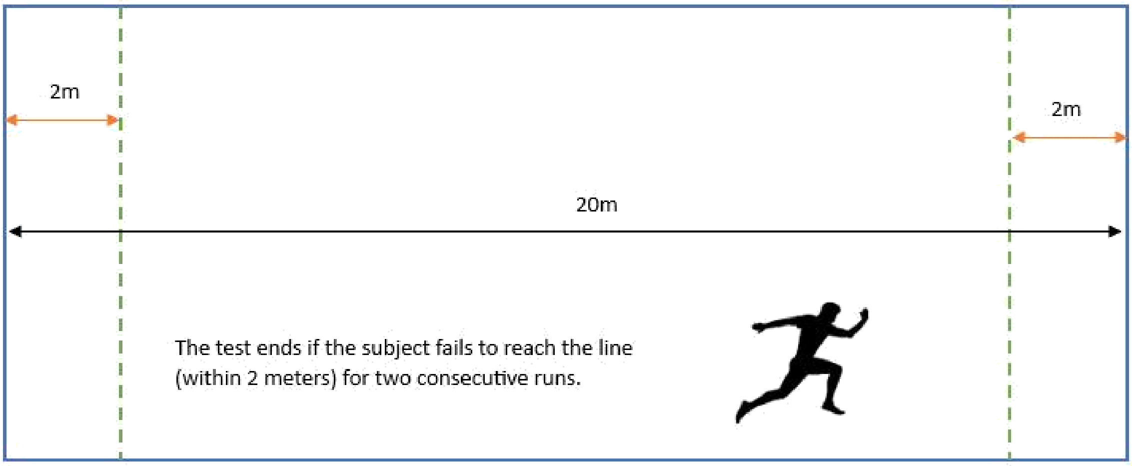

Figure 4. Graphic Representation of the Endurance Shuttle Run Test.

3.2.4.3 Power Assessment

For the power assessment, two different tests were used. For upper limb power, the 3 kg Sitting Medicine Ball Throw Test (SMBT) (97,98) was used, while the SBJ (83) was applied to assess lower limb power.

For the 3 kg SMBT (97,98) test subjects were asked to sit on a chair placed against a wall. A tape measure was placed on the ground at the front end of the subjects' chair and stretched out to 10m. Subjects are instructed to sit in the chair with their backs against the chair for support and their feet flat on the ground. To account for different arm lengths of the subjects, they were asked to sit in the chair and hold the ball in both hands with their arms extended away from their chests. They are then instructed to drop the ball straight down on to the tape measure. The tape was adjusted so that this point is the zero mark.

Three practice trials were then provided at which time they were instructed to push the ball away from the center of their chest as far as possible, using a similar motion to a basketball chest pass. A 3- min rest was given between the practices and the actual test.

Next, for the actual test, subjects grasped the medicine ball and are instructed to forcefully push the ball away from the center of their chest as far as possible, again using a motion like a basketball chest pass.

The spot where the front end of the ball hit the measuring tape was recorded. Subjects performed three trials with a 3-kg ball, with a 90-second rest between trials. The mean score of the three trials was used for analysis (99). A graphic representation of the test is shown in figure 5.

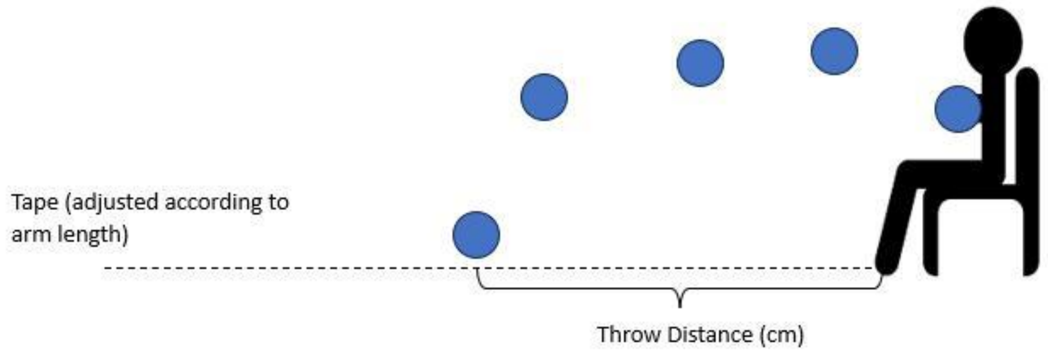

Figure 5. Graphic Representation of the 3-kg Medicine Ball Throw Test.

To assess lower limb strength, the athletes performed the SBJ test. In this test, the athlete stands behind a line marked on the ground with feet slightly apart. A two-foot take-off and landing is used, with swinging of the arms and bending of the knees to provide forward drive. The subject attempts to jump as far as possible, landing on both feet without falling backwards. One practice attempt was allowed followed by a 30 second rest. After resting, the real test begun, and athletes had three attempts. The measurement is taken from the take-off line to the nearest point of contact on the landing (back of the heels). The longest distance jumped out of the three attempts was recorded. Between each attempt, athletes rested for 30 seconds (100). A graphic representation of this test is shown in figure 6.

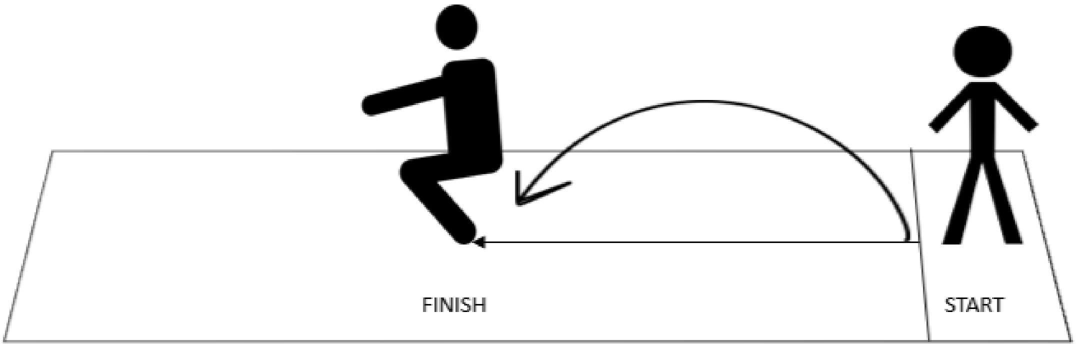

Figure 6. Graphic Representation of the Standing Broad Jump Test.

3.2.4.4 Agility Assessment

Agility was assessed through the 4-corner Agility Test (101). Four up-turned shuttlecocks were placed in each of the four corners of the court. The participants begin from the central base, move around the four corners of the court for a total of 16 repetitions (four times each corner), and using their dominant hand, struck the shuttlecocks in order in sectors A, B, C, and D (as depicted in Figure 9), returning to the central base after striking each shuttlecock. Left-handed athletes move around the court in the opposite direction, striking first the shuttlecock placed in sector C, then D, A and finally B (as depicted in Figure 7).

Before the test started, subjects assumed their badminton playing ready position on the central base of the court facing the net (without a racket in hand). The test starts and hand timing initiates immediately when the athletes begin to move from the central base. For the tester to stop the stopwatch and for a trial to be valid, at least one of the player's feet must return to the central base. Recordings were taken by the investigator, with a stopwatch with an accuracy of 0.01 s. Participants performed the test twice and only the best performance time recorded was included in the analysis. Athletes rested for 5 min between each trial (59). A graphic representation of the test utilized is shown in figure 7.

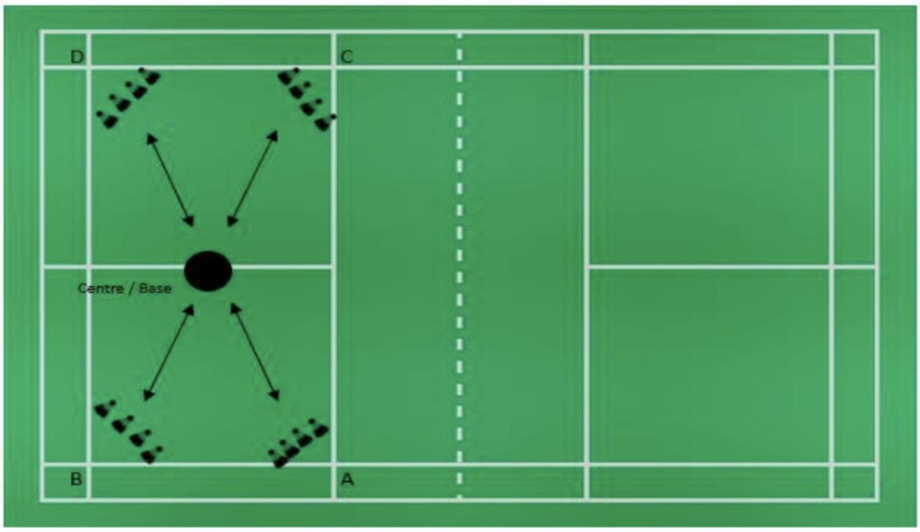

Figure 7. Graphic Representation of the 4-Corner Agility Test.

3.2.4.5 Warm-up Protocol

As shown in table 4, before the start of the assessments on the first day (of each group), a short warm-up protocol was applied. The goal of this protocol is to generate an increase in muscle temperature that allows for various internal changes to occur, such as increased blood flow and optimized metabolic responses (102). The benefits of warm-up and re-warm-up protocols have been documented in the literature (103). Despite this, there is still some scarcity regarding how to apply these protocols for badminton players prior to physical fitness testing, therefore, a simple warm-up protocol for this study was designed.

Table 4. Warm-up protocol applied.

- Light Jog – 3'
- Forward Arm Rotations– 20 repetitions
- Backwards Arm Rotations – 20 repetitions
- Skipping – 20 seconds
- Knees to the Chest – 20 seconds
- Articular Mobility

3.2.5 Variables Presentation

The variables analysed in the present study are listed in table 5. Variables were grouped into Biosocial Data, Body Composition (split by whole body and regional body analysis) and Field Tests Performance. Table 5 also briefly describes each variable and what unit of measurement was used.

Table 5. List and description of studied variables in the present study.

Variables	Abbreviation	Unit of Measurement	Description
Biosocial Data			
Age	-	Years	Age of the participants.
Sex	-	-	Sex of the participants.
Weekly Training Volume	-	min	Amount of badminton specific training done per week.
Years of Practice	-	Years	Amount of time an athlete has practiced badminton.
Whole-Body Analysis			
Body Mass	BM	kg	Body mass of the whole body.
Body Fat	BF	%	Body fat of the whole body.
Skeletal Muscle Mass	SMM	kg	Amount of muscle that is attached to the skeleton.
Height	-	m	Measurement of a subject from bottom to top.
Body Mass Index	BMI	Kg/m^2	Amount of body mass relative to height.
Body Water	BW	l	Total amount of water in the body.
ECW/TBW	-	-	Proportion of water that is outside of the body's cells relative to the total amount of water in the body.
Regional Body Analysis			
Right Arm Lean Mass	RALM	kg	Amount of lean tissue in the right arm.
Left Arm Lean Mass	LALM	kg	Amount of lean tissue in the left arm.
Right Leg Lean Mass	RLLM	kg	Amount of lean tissue in the right leg.
Left Leg Lean Mass	LLLM	kg	Amount of lean tissue in the left leg.
Trunk Lean Mass	TLM	kg	Amount of lean tissue in the trunk.
Field Tests Performance			
Agility	-	Sec	Ability to move quickly and easily often involving rapid changes in direction.
Cardiovascular Endurance	CE	n	Ability to sustain prolonged exercise without fatigue.
Lower Limb Explosive Power	-	m	Ability of the muscles in the lower body to generate force rapidly.
Upper Limb Explosive Power	-	m	Ability of the muscles in the upper body to generate force rapidly.

3.3 Results

Mean values for all studied variables are presented in Table 6 for female subjects and in table 7 for male subjects.

Table 6. Descriptive data of the Portuguese Badminton Female National Team Athletes (n=10)

Variables	Mean ± sd*	Min. – Max.
Biosocial Data		
Age, yr (median, yr)	23.4 ± 2.9 (24.0)	18.8 – 29.4
Sex, n female (% female)	10 (43.5)	
Weekly Training Volume, min (median, min)	534 ± 296.2 (495)#	240 - 1260
Years of Practice, yr (median, yr)	12.5 ± 2.9 (11.5)	9 – 17
Whole-Body Analysis		
Body Mass, kg, (median, kg)	69.3 ± 11.5 (67.7)*&	54.2 – 90.3
Body Fat, %, (median, %)	27.6 ± 4.6 (27.8)	20.7 – 32.3
Skeletal Muscle Mass, kg, (median, kg)	29.0 ± 4.4 (27.8)	23.8 – 34.5
Height, m, (median, m)	1.66 ± 0.1 (1.66)	1.59 – 1.74
Body Mass Index, Kg/m^2, (median, Kg/m^2)	24.9 ± 2.9 (24.5)*	21.2 – 29.8
Body Water, l, (median, l)	37.9 ± 5.5 (36.4)	31.4 – 44.7
ECW/TBW	0.372 ± 0.005 (0.373)	0.364 – 0.379
Regional Body Analysis		
Right Arm Lean Mass, kg**,** (median, kg)	2.79 ± 0.55 (2.65)	2.21 – 3.52
Left Arm Lean Mass, kg, (median, kg)	2.58 ± 0.53 (2.43)	2.05 – 3.28
Right Leg Lean Mass, kg, (median, kg)	8.03 ± 1.37 (7.71)	6.18 – 9.66
Left Leg Lean Mass, kg, (median, kg)	7.88 ± 1.23 (7.62)	6.22 – 9.35
Trunk Lean Mass, kg, (median, kg)	22.6 ± 3.3 (21.8)	19.0 – 26.9
Field Tests Performance		
Agility, sec, (median, sec)	33.4 ± 2.1 (34)	29.8 – 36.3
Cardiovascular Endurance, n, (median, n)	47 ± 22 (42)	23 – 91
Lower Limb Explosive Power, m, (median, m)	1.91 ± 0.15 (1.92)	1.66 – 2.10
Upper Limb Explosive Power, m, (median, m)	2.67 ± 0.27 (2.64)	2.33 – 3.27

#p<0.01 in the one sample t-test comparison (Weekly Training Volume Spanish (104)).

* p<0.05 in the one sample t-test comparison (BM Polish (66), Turkish (25); BMI Polish (66), Turkish (25)).

& p=0.05 in the one sample t-test comparison (BM Spanish (104)).

Table 7. Descriptive data of the Portuguese Badminton Male National Team Athletes (n=13)

Variables	Mean ± sd	Min. – Max.
Biosocial Data		
Age, yr (median, yr)	21.2 ± 3.5 (21.8) #	15.3 – 29.4
Sex, n male (% male)	13 (56.5)	
Weekly Training Volume, min (median, min)	654.2 ± 396.1 (525)#	180 - 1710
Years of Practice, yr (median, yr)	11.9 ± 4.4 (10)	8 – 23
Whole-Body Analysis		
Body Mass, kg, (median, kg)	71.0 ± 6.7 (73)#	59.9 – 78.9
Body Fat, %, (median, %)	8.4 ± 1.9 (8.3)#	6.0 – 10.9
Skeletal Muscle Mass, kg, (median, kg)	37.3 ± 4.5 (39.3)	30.1 – 41.4
Height, m, (median, m)	1.80 ± 0.05 (1.79)#*	1.72 – 1.91
Body Mass Index, Kg/m^2, (median, Kg/m^2)	21.8 ± 1.8 (21.6)#	19.1 – 24.7
Body Water, l, (median, l)	47.3 ± 5.4 (49.6)	38.9 – 52.0
ECW/TBW	0.368 ± 0.004 (0.361)	0.359 – 0.368
Regional Body Analysis		
Right Arm Lean Mass, kg**,** (median, kg)	3.6 ± 0.6 (3.9)	2.8 – 4.1
Left Arm Lean Mass, kg, (median, kg)	3.4 ± 0.6 (3.7)	2.6 – 3.9
Right Leg Lean Mass, kg, (median, kg)	10.3 ± 1.1 (10.7)	8.6 – 11.4
Left Leg Lean Mass, kg, (median, kg)	10.2 ± 1.0 (10.4)	8.5 – 11.3
Trunk Lean Mass, kg, (median, kg)	27.6 ± 3.2 (29.4)	22.6 – 30.2
Field Tests Performance		
Agility, sec, (median, sec)	27.8 ± 1.9 (27.5)#	24.1 – 30.5
Cardiovascular Endurance, n, (median, n)	104 ± 16 (102)	71 – 127
Lower Limb Explosive Power, m, (median, m)	2.54 ± 0.17 (2.49)	2.27 – 2.87
Upper Limb Explosive Power, m, (median, m)	4.34 ± 0.61 (4.4)	3.13 – 5.44

# $p<0.01$ in the one sample t-test comparison (age (105); BM Polish (66) , Turkish (25); Height Polish (66); Weekly Training Volume (104); BMI Turkish (25); BF Turkish (25); BF Portuguese 2018 (106); Agility Polish (59)).

* $p<0.05$ in the one sample t-test comparison (Height Turkish *(25)).

3.3.1 Biosocial Data

In this subsection 3.3.1., results for the biosocial data are reported. The values that were obtained, were self-reported by the subjects via questionnaire (annex 3).

Parameters included in this category are: Age; Sex; Weekly Training Volume; Years of Practice. The results show that 56.5% of the sample is comprised of male individuals, while 43.5% represents the female sample. The female subject's ages are between 18.8 and 29.4 years old, while the male subject's ages lie between 15.3 and 29.4 years old. The female subject's age average is 23.4 years old, while the male average is a little below at 21.2 years old. As for years of practice, all individuals have at least 8 years of experience practicing badminton, and one individual has 23 years of experience. The female average is 12.5 years, while the male average is 11.9. Regarding weekly training volume, results range from 180 to 1710 min per week with female subjects having an average of 534 min per week while male subjects have an average weekly training volume of 654.2 min per week.

When comparing the data from this study and data from the available literature we can determine that on average, male subjects are the same age as their female counterparts (21.2 yrs vs 23.4 yrs. $p=0.133$). Despite this, there is also a bigger disparity between the ages of the male subjects due to the youngest athlete being only 15.3 years old and the oldest athlete being 29.4 years old. The current available literature shows that in 2020, the mean age of the top 100 male athletes in the World Ranking was 26.3 years old, while the mean age of the top 100 female athletes was 24.7 years old (106). This shows that male Portuguese elite badminton players are still on average younger than the average of the top 100 male athletes in the world (21.2 yrs vs 26.3 yrs, respectively. $p<0.01$). Meanwhile, female Portuguese elite badminton players are on average the same age as the top 100 female athletes in the world (23.4 yrs vs 24.7 yrs, respectively. $p=0.225$).

Male Portuguese elite badminton players are also shown to, on average, accumulate the same weekly training volume as their female counterparts (654.2 min vs 534.0 min, respectively. $p=0.432$). There is not much literature available surrounding the ideal weekly training volume for specific badminton training, meanwhile, one study showed that male Spanish elite badminton players trained on average 810 min per week (49), while other that involved both male and female Spanish elite athletes, showed that the male athletes trained on average 1080 min per week while their female counterparts trained on average 1192 min per week spread around 5 weekly training sessions(104). While these findings suggest that, on average, both male (654.2 min vs 1080.0 min. $p=0.002$) and female (534.0 min vs 1192.0 min, respectively. $p<0.001$)

Portuguese elite athletes train less per week than Spanish elite athletes, more evidence is necessary in order to compare the Portuguese reality with other countries. Finally, regarding years of badminton practice, on average, male Portuguese elite badminton players have 11.9 years of practice, while female athletes have 12.5.

3.3.2 Whole Body Analysis

In the present subsection, the results of the whole-body analysis are reported. Parameters included in this category are: BM; BF; SMM; Height; BMI; Body Water; ECW/TBW. The results show that female subjects BM ranges between 54.2 and 90.4 kg with an average of 69.3 kg, while male subjects BM ranges between 59.9 and 78.9kg, with an average of 71 kg. The average BF of female subjects is 27.6% with values ranging between 20.7 and 32.3%. Male athletes' BF ranges between 6.0% and 10.9% with an average of 8.4%. In regard to SMM, the female subjects' values are between 23.8 and 34.5 kg while the average value is 37.3 kg. As for the male subjects, the individual with the highest SMM reported a value of 30.1 kg while the lowest, reported a value of 41.4 kg. The average for the male SMM is 37.3 kg. Regarding height, female values ranged between 1.59 meters (m) and 1.74 m, while the male values ranged between1.72 m and 1.91 m. The average for the female height is 1.66m and for the males, 1.80m. As for BMI, values ranged between 19.1 Kilogram per square meter (Kg/m2) and 29.8 Kg/m2. The female subject's average BMI was 24.9 Kg/m2 while the male average BMI was 21.8 Kg/m2. The average value for the female subject's body water was 37.9 liters (l), with values ranging from 31.4 l and 44.7 l. Meanwhile, the average value for the male subject's body water was 47.3 l, with values ranging from 38.9 l and 52.0 l. Finally, concerning the ECW/TBW, female athletes had a mean value of 0.372, with values going from 0.364 to 0.379. The male athletes had a mean value of 0.368, with values ranging from 0.359 and 0.368.

When comparing data from this study regarding whole-body parameters and data from the available literature, female athletes are shown to be on average, the same height as Spanish elite female athletes (1.66m vs 1.65m, respectively. $p = 0.453$ in one-sample t-test), but on the flipside, heavier (69.30 kg vs 61.10 kg, respectively. $p= 0.05$ in one-sample t-test) (104).

As for, comparing the male individuals to the Spanish elite male athletes on the aforementioned study, we found that, there was no significant difference between average weight (71.0 kg vs 71.7 kg, respectively. $p = 0.718$ in one-sample t-test) nor average height (1.80m vs 1.78m, respectively. $p= 0.116$). When comparing these results with a study made with Polish elite badminton players (66), we found that although there is no significant difference between female athlete's average heights (1.66m vs 1.64m, respectively. $p= 0.211$), the Polish athletes are lighter than the Portuguese athletes (59.8kg vs 69.3kg, respectively. $p=0.029$).

As for the male athletes, Portuguese athletes are shown to be, on average, shorter (1.80m vs 1.85m, respectively. $p=0.005$) and lighter (71.0 kg vs 77.27 kg, respectively. $p=0.005$) than the Polish athletes. Another study that used Turkish elite badminton players (25) showed the same results as the previously mentioned study using polish athletes, regarding the female subjects. Turkish female elite badminton players are, on average, lighter than the Portuguese athletes (55.0kg vs 69.3kg, respectively. $p=0.002$) and no significant difference was found between their average heights (1.64m vs 1.66m, respectively. $p=0.211$). As for the male athletes, the Portuguese badminton elite athletes are on average heavier than the Turkish athletes (71.0kg vs 63.2kg, respectively. p=0.001) and taller (1.80m vs 1.77m, respectively. p=0.032).

When comparing the BMI of Portuguese athletes with Polish and Turkish athletes, we found that the Portuguese female athletes have a higher BMI when compared to both Polish (24.9 kg/m2 vs 22.2 kg/m2, respectively. p=0.016) and Turkish (24.9 kg/m2 vs 20.4 kg/m2, respectively. p<0.001) female elite badminton players.

As for the male badminton players, there was, on average, no significant difference between the BMI of Portuguese elite badminton players and Polish elite badminton players (21.8 kg/m2 vs 22.7 kg/m2, respectively. p=0.100). This may mean that despite the height and weight differences, their proportion is somehow similar. Meanwhile, when comparing Portuguese male elite badminton players with Turkish male elite badminton players, the Portuguese athletes are shown to have on average, a higher BMI (21.8 kg/m2 vs 20.1 kg/m2, respectively. p=0.004). Even though the Turkish athletes present lower values for both weight and height, the difference in weight seems to be larger, meaning that this may result in differences in other body composition parameters.

When analysing the Portuguese elite badminton player's BMI, we can observe that on average, male subjects are on the healthy range. Female athletes are also, on average, on a healthy BMI range, meanwhile, this average value is very close to the overweight range.

When comparing the Portuguese elite female players to Turkish elite female badminton players, no significant difference was found regarding BF (27.6% vs 25.4%, respectively. p=0.291). The opposite is verified for their male counterparts, with the Portuguese athletes presenting significantly lower levels of BF when compared with Turkish athletes (8.4% vs 14.2%, respectively. p<0.001).

Meanwhile, when compared with Spanish elite male badminton players (49), no significant differences were found between BF levels (8.4% vs 8.3%, respectively. p=0.861). Also, when compared with data from 2018 (106), also featuring Portuguese male elite badminton players, the BF of the current elite male athletes seems to be lower (8.4% vs 13.1%, respectively. p<0.001).

When referring to body water levels, Portuguese elite male badminton players appear to have more body water than Portuguese elite female badminton players (47.3l vs 37.9l, respectively. p=0.01).

The same was verified for SMM, with male athletes presenting higher levels when compared to their female counterparts (37.3kg vs 29.0kg, respectively. p=0.007).

Finally, concerning the ECW/TBW, the subjects of the present study are, on average, on the normal range. No cutoff values for badminton players were found but the fact that these values are in the normal range is a good sign because lower levels of intracellular water have been found to lower performance (namely, grip strength) in judo athletes (107).

3.3.3 Regional Body Analysis

In this subsection, results for the of the regional body analysis are reported. Parameters included in this category are: Right Arm Lean Mass; Left Arm Lean Mass; Right Leg Lean Mass; Left Leg Lean Mass; Trunk Lean Mass. As it pertains to the right arm lean mass, female subjects had an average value of 2.8 kg, while the male subjects presented an average value of 3.6 kg. The values of the female subjects ranged from 2.2 kg to 3.5 kg, while the male subjects' values ranged between 2.8 kg and 4.1 kg. As for the left arm lean mass, the female subject's average value was 2.6 kg, while the male's average value was 3.4 kg. Female values ranged between 2.1 kg and 3.3 kg, and the male values ranged between 2.6 kg and 3.9 kg. Regarding the legs lean mass, female subjects presented left leg lean mass values between 6.2 kg and 9.4 kg, with a mean value of 7.9 kg. The male subjects left leg lean mass values ranged between 8.5 kg and 11.3 kg with a mean value of 10.2 kg. As for the right leg, female subjects had values ranging from 6.2 kg to 9.7 kg, while the male subjects had values ranging between 8.6 kg and 11.4 kg. The mean average value for the female subject's right leg lean mass was 8.0 kg, while the males was 10.3 kg. Lastly, regarding the trunk lean mass, female subjects presented values between 19.0 kg and 26.9 kg, with an average value of 22.6 kg, while the male subjects presented values between 22.6 kg and 30.2 kg and a mean value of 27.6 kg.

In our research, no data was found in badminton players from other countries, regarding regional body composition analysis.

3.3.4 Field Tests Performance

In subsection 3.3.4., the results of the four field tests applied are reported. Parameters included in this category are: Agility; Cardiovascular Endurance; Lower Limb Explosive Power; Upper Limb Explosive Power. Results show that regarding agility, the average time taken by female subjects to complete the test was 33.4 seconds. The fastest subject to complete the test took 29.8 seconds, while the slowest took 36.3 seconds. As for the male subjects, the average time taken to complete the test was 27.8 seconds. The fastest subject to complete the test took 24.1 seconds, while the slowest took 30.5 seconds. Regarding the performance of female subjects in the cardiovascular endurance testing, the average number of levels completed was 47 with values ranging from 23 to 91 levels completed. As for the performance of male subjects in the same test, the average number of levels completed was 104, with values ranging from 71 to 127 levels completed.

As it pertains to lower limb power, female subjects had an average distance jumped of 1.91 m, with jump distances ranging from 1.66 m to 2.10 m. The male subjects had an average distance jumped of 2.54 m, with jump distances ranging from 2.27 m to 2.87 m.

Lastly, regarding upper limb power, the average female subject throw distance was 2.67 m, with throw distances ranging from 2.33 m to 3.27 m. As for the male subjects, the average throw distance was 4.34 m, with throws distances ranging from 3.13 m to 5.44 m.

When analysing the performance of the Portuguese elite badminton players in the field tests that were applied, we can observe that overall, the male athletes tend to, on average, present different values from their female colleagues.

Regarding agility, the male elite badminton players performed the test faster than the female elite badminton players (27.8 sec vs 33.4 sec, respectively. $p<0.001$). Meanwhile when comparing the male elite Portuguese badminton players, with Polish elite male badminton players (59), the Portuguese players were also faster (27.8 sec vs 30.1 sec, respectively. $p<0.001$).

When comparing male and female results in the present study, regarding cardiovascular endurance, we can also see that, on average, the male athletes completed more levels (thus performed better) than female athletes (104 vs 47, respectively. $p<0.001$).

As for upper and lower limb explosive power, no studies were found with elite badminton players, in order to compare the results of this study with other elite athletes from other countries. Comparing the results of the Portuguese male and female elite badminton players, we found that male athletes seem to have better results than their female counterparts in both upper (4.34 m vs 2.67 m, respectively. $p<0.001$) and lower (2.54 m vs 1.91 m, respectively. $p<0.001$) limb explosive power.

3.4 Discussion

To our knowledge, this is the first study to focus on characterizing elite Portuguese badminton players regarding four different fitness markers. There is some similar literature available, particularly a dissertation (106) that focused on anthropometric evaluation, detailed body composition, and bio-motor capacity through the Isokinetic knee extensors and flexors muscles testing. It differs from this study in the sense that the present study although also focusing on body composition analysis, it focuses on other markers of physical fitness such as agility, cardiovascular endurance, and upper and lower limb explosive power instead of bio-motor capacity.

Based on the results of this study and while these findings may be circumstantial, it can possibly demonstrate that Portuguese male athletes still have not reached their prime and may potentially have a bigger development window in the future due to their young age when compared to international literature (106). Meanwhile it is also shown that when compared to elite Spanish players, Portuguese elite badminton players, on average train less.

Despite not many data existing regarding what is the recommended training volume per week, this can potentially be hindering the development of our players, or at least not potentiating them to the fullest.

Based on the current study's findings, if non-elite Portuguese badminton players wish to reach higher levels, it may be recommended that they try to accumulate at least around 534 min, for females, and 654.2 min, for males, of badminton specific training, spread around a whole week.

The data surrounding the average age and average years of practice may suggest that female athletes started playing at around age 10 and male athletes at around 9 years old. These results are in line with previous findings, also on Portuguese elite badminton players, showing that on average those athletes had 11.5 years of training experience (106).

Regarding the whole-body analysis of this study, Portuguese male elite badminton athletes appear to be similar to international athletes, namely, Turkish, Polish and Spanish. Meanwhile, female elite badminton athletes appear to have some differences when compared to their Turkish, Polish and Spanish counterparts. While their height is on average, similar, their body weight is on average, superior. This may suggest that differences in body composition are present.

In regard to the field test applied in this study, based on our research of the available literature, very limited data is available. Therefore, a comparison between the male and female Portuguese badminton elite athlete's results was done. The male athletes appear to have overall better performances than their female counterparts. Although this comparison is not representative to extract meaningful conclusions, it can serve to raise the hypothesis that Portuguese female badminton athletes may be, on average not as physically apt as their male counterparts.

The absence of reference values in the available literature, regarding the analysis of the regional body markers and the field tests applied in this study, may mean that the results found in the current study should be used for that intended purpose, serving as references values for badminton players in Portugal and potentially, internationally.

The main strength of this study is the ease of use of the battery of tests applied, which can be easily adopted and used by coaches and athletes, providing meaningful data without needing specific and expensive equipment. Another strength of this study is that the sample encompasses the elite Portuguese national badminton team. Although this is a strength, the sample is also small, which reduces statistical power. Sadly, another limitation is a malfunction that occurred with the InBody S10 device during the body composition assessment that took place during the 4th day of the intervention, which corrupted the data of these markers for the athletes that were tested in that day, creating a larger reduction in the sample size.

3.5 Conclusions

To our knowledge, this is the first study to publish reference values for elite Portuguese badminton players, regarding body composition, agility, cardiovascular endurance, and both upper and lower limb explosive power.

The current lack of available literature regarding reference values for the aforementioned markers may hinder the work of coaches and athletes in increasing their performance. Accordingly, the publication of the reference values found in the current study may contribute to a more scientific based approach to training of Portuguese athletes. The goal of this study was also to publish a battery of tests that can be easily applicable in the field by Portuguese coaches and athletes, without needing many resources, and still get good feedback regarding their athletic performance, benefitting from reference data of elite athletes of their country.

Chapter 4 – Study 3: "Usefulness of Key Fitness Markers for the Prediction of Portuguese National Team Badminton Players Performance and Ranking"

Abstract

There are numerous performance factors in badminton, with physical fitness being a key component of the sport. Therefore, it becomes important to understand which physical fitness markers best correlate with performance in badminton. **PURPOSE:** The aim of this study was to analyse the association between different fitness markers and athlete's performance in the Portuguese National Badminton Team. **METHODS:** 23 elite level Portuguese Badminton players were tested in four different fitness markers (agility, body composition, power, and cardiovascular endurance). The assessments were made over four days in a Portuguese National Badminton Team internship. Performance was assessed through a formula created to more accurately depict it. Partial and semi-partial correlations were performed to assess the relations between dependent and independent variables. **RESULTS:** A significant correlation was found between the performance in singles and the performance in doubles in both male and female athletes. A negative significant correlation between lower limb power and mixed doubles performance in female athletes was also found. Additionally, SMM, body water and all the segmental body composition markers appear to have a significant correlation with mixed doubles performance. Some borderline results warrant further research. **CONCLUSION:** Athletes who wish to improve their performance in the singles event, should also play the doubles event and/or vice-versa. Overall, athletes should focus on increasing their SMM (across all segments) and their body water, to increase mixed doubles performance.

4.1 Introduction

Badminton is a sport that involves many high intensity movements, which include fast court movements, accelerations, decelerations, and quick changes of direction over short distances, all of which require the whole body to produce maximum power (87,88). It also includes high levels of mental acuity and technical skill (7). Due to its nature, badminton is a sport that while being very physically demanding, it forces athletes who seek to reach elite levels to improve all eleven physical fitness markers. This is consistent with more literature that suggests that the most important characteristics of athletes in badminton are technical skill, physical performance capacity and anthropometrical factors (40). Despite being such a popular sport worldwide, badminton is predominantly played in Asian countries, as there is more investment in the sport, and it is also deeper rooted in the culture of the population.

There are many ways to assess an athlete's performance during a specific period. Regarding badminton in Portugal, the standardized way to assess overall performance is through the national rankings or a list of athletes organized based on their relative strength (108). Despite not being a perfect metric, it reflects the performance of each player throughout the season. Some literature suggests that ranking lists are a reliable tool for predicting performance in many individual sports, for example, swimming (109). In Portugal, there are rankings for non-senior athletes (divided by age), veteran athletes (divided by age) and senior athletes (divided by level of play). Each athlete that during the present season competes in zonal or national competitions existing in the Portuguese Badminton Federation's calendar will be ranked accordingly, in due of their performance during tournaments. Regarding non-senior and senior athletes, there are two distinct rankings: zonal and national. Zonal rankings are divided on six different "sub-rankings" based on geographic locations, specifically, North, South, Centre, Lisbon, Azores, and Madeira. Each of the previously mentioned location has their own tournaments and athletes from each different location are ranked in regards of the 4 individual zonal tournaments. Meanwhile, national rankings will be established by the summation of the nine best scores attained by each athlete in the National Seniors Circuit competitions (Zonal Phase, National, Club Tournaments, National Senior Team Championships and National Senior Championship) and competitions of the International Circuit of Seniors and Para badminton (competitions under the scope of Badminton Europe and Badminton World Federation) (11).

A myriad of performance factors in badminton exist, showing the high degree of complexity of the sport.

The literature suggests that the most important characteristics of athletes in badminton are technical skill, physical fitness and anthropometrical factors (41). Unfortunately, due to the lack of descriptive data regarding physical fitness and performance in badminton, this vital component is many times sub valued by athletes and coaches, who focus primarily on skill training (90).

Due to the development of new technologies, performance analysis has become a critical part of an athlete's development, coaching process, and is considered provide a substantial competitive advantage (90). Sadly, even though performance analysis keeps evolving at a fast pace and the need for coaches and athletes to keep up with this advancement (91), a gap in the literature still exists, regarding a big component of performance analysis, namely, physical fitness testing for badminton players.

With the importance of physical fitness established regarding sports performance, it is important that coaches and elite athletes have access to raw data regarding their performance on certain markers of physical fitness.

A valid question to ask would be: "What is the physical fitness marker that best correlates with performance in elite badminton players?" Despite the importance of this question, when analysing the present literature, we quickly discover that most of the data related to performance and badminton is more focused on match analysis and the biomechanics of specific strokes and movements of the sport. Research focused on testing of physical fitness markers and badminton performance is somewhat limited and consequently, few valid conclusions can be drawn. Based on this, it is important that more research in this topic is provided due to the very specific fitness requirements of the sport (92). In Portugal the literature is very scarce regarding badminton and physical fitness, but international research shows us that there is a big correlation between these two variables (93). Therefore, due to this scarcity in the Portuguese literature, it may be hard to create a profile of the elite Portuguese badminton player.

Therefore, given the current limitations present in the literature, and the need to further contribute to advances in the research of physical fitness in badminton, the aim of this study is to analyse the association between different fitness markers (agility, body composition, power, and cardiovascular endurance), biosocial data, and athlete's performance in the Portuguese national badminton team.

4.2 Materials and Methods

This study evaluated the physical fitness markers of athletes and correlated the results with their performance. Physical fitness was assessed following the same methods detailed in chapter 3 (study 2). Physical performance was obtained following a formula created in order to better depict the performance of athletes and make a fairer assessment of the athletes' output. The formula is as follows:

Performance = Number of points gathered during the season in each event / Number of events in which the athlete participated during the season.

This study deserved the approval of the Ethics Committee of the Santarém Polytechnic University under the code Nº2-2024ESDRM.

4.2.1 Statistical Analysis

Descriptive statistics are presented as mean ± sd and range, for all analysed variables. The Gaussian distribution of the data was assessed with the Shapiro-Wilk goodness-of-fit test. Pearson correlation test was applied in order to evaluate the relationship between variables. Only correlation coefficients equal or above 0.50 were considered to be significant at a significance level of 5% and a statistical power of 80% (110). Statistical calculations were performed using the IBM SPSS Statistics version 24 (IBM Corp, Armonk, NY, USA).

4.3 Results

The studied correlations and significance values are shown for male athletes in table 8, for female athletes in table 9 and for the whole sample (not split by gender), in table 10.

Table 8. Pearson Correlation and Significance Values for Male Athletes.

Male		**Pearson Correlation**	**Sig (2 Extremities)**	N
Cardiovascular Endurance (n)	Performance SH	0.379	0.201	13
	Performance PH	0.092	0.765	13
	Performance PM	0.247	0.464	11
Lower Limb Power (m)	Performance SH	0.153	0.617	13
	Performance PH	-0.088	0.774	13
	Performance PM	0.479	0.136	11
Upper Limb Power (m)	Performance SH	0.039	0.898	13
	Performance PH	0.177	0.563	13
	Performance PM	0.573	0.065	11
Agility (sec)	Performance SH	-0.432	0.140	13
	Performance PH	-0.321	0.286	13
	Performance PM	-0.336	0.312	11
Height (m)	Performance SH	0.266	0.380	13
	Performance PH	0.375	0.207	13
	Performance PM	0.343	0.302	11
Body Mass (kg)	Performance SH	-0.087	0.778	13
	Performance PH	-0.048	0.876	13
	Performance PM	0.418	0.200	11
Body Mass Index (kg^{m2})	Performance SH	-0.288	0.340	13
	Performance PH	-0.318	0.289	13
	Performance PM	0.275	0.413	11

**. The correlation is significant at the 0,01 level (2 extremities).

*. The correlation is significant at the 0,05 level (2 extremities).

Table 8. Pearson Correlation and Significance Values for Male Athletes (Continuation).

Male		Pearson Correlation	Sig (2 Extremities)	N
Body Fat (%)	Performance SH	-0.143	0.760	7
	Performance PH	0.062	0.896	7
	Performance PM	0.015	0.975	7
Skeletal Muscle Mass (kg)	Performance SH	-0.249	0.590	7
	Performance PH	-0.028	0.952	7
	Performance PM	0.572	0.180	7
Body Water (l)	Performance SH	-0.231	0.619	7
	Performance PH	-0.002	0.997	7
	Performance PM	0.584	0.168	7
ECW/TBW	Performance SH	0.414	0.356	7
	Performance PH	0.498	0.256	7
	Performance PM	0.003	0.994	7
Right Arm Lean Mass (kg)	Performance SH	-0.216	0.642	7
	Performance PH	0.026	0.956	7
	Performance PM	0.489	0.265	7
Left Arm Lean Mass (kg)	Performance SH	-0.130	0.781	7
	Performance PH	0.085	0.856	7
	Performance PM	0.512	0.240	7
Right Leg Lean Mass (kg)	Performance SH	-0.083	0.859	7
	Performance PH	0.066	0.888	7
	Performance PM	0.741	0.057	7
Left Leg Lean Mass (kg)	Performance SH	-0.047	0.920	7
	Performance PH	0.103	0.825	7
	Performance PM	0.741	0.057	7
Trunk Lean Mass (kg)	Performance SH	-0.150	0.748	7
	Performance PH	0.079	0.867	7
	Performance PM	0.537	0.214	7

**. The correlation is significant at the 0,01 level (2 extremities).

*. The correlation is significant at the 0,05 level (2 extremities).

Table 8. Pearson Correlation and Significance Values for Male Athletes (Continuation).

Male		**Pearson Correlation**	**Sig (2 Extremities)**	N
Performance SH (Points/Nº Tournaments)	Performance SH	1		13
	Performance PH	0.694**	0.008	13
	Performance PM	0.034	0.922	11
Performance PH (Points/Nº Tournaments)	Performance SH	0.694**	0.008	13
	Performance PH	1		13
	Performance PM	0.066	0.847	11
Performance PM (Points/Nº Tournaments)	Performance SH	0.034	0.922	11
	Performance PH	0.066	0.847	11
	Performance PM	1		11

**. The correlation is significant at the 0,01 level (2 extremities).

*. The correlation is significant at the 0,05 level (2 extremities).

Table 9. Pearson Correlation and Significance Values for Female

Female		**Pearson Correlation**	**Sig (2 Extremities)**	N
Cardiovascular Endurance (n)	Performance SS	0.279	0.435	10
	Performance PS	0.298	0.403	10
	Performance PM	-0.641	0.063	9
Lower Limb Power (m)	Performance SS	-0.160	0.659	10
	Performance PS	-0.123	0.736	10
	Performance PM	-0.666*	0.050	9

**. The correlation is significant at the 0,01 level (2 extremities).

*. The correlation is significant at the 0,05 level (2 extremities).

Table 9. Pearson Correlation and Significance Values for Female Athletes (Continuation).

Female		Pearson Correlation	Sig (2 Extremities)	N
Upper Limb Power (m)	Performance SS	0.216	0.549	10
	Performance PS	0.488	0.153	10
	Performance PM	-0.451	0.224	9
Agility (sec)	Performance SS	-0.482	0.159	10
	Performance PS	-0.463	0.178	10
	Performance PM	0.521	0.150	9
Height (m)	Performance SS	0.183	0.612	10
	Performance PS	0.107	0.770	10
	Performance PM	0.244	0.528	9
Body Mass (kg)	Performance SS	-0.033	0.928	10
	Performance PS	-0.045	0.901	10
	Performance PM	0.132	0.735	9
Body Mass Index (kg^{m2})	Performance SS	-0.165	0.649	10
	Performance PS	-0.129	0.722	10
	Performance PM	0.050	0.898	9
Body Fat (%)	Performance SS	-0.068	0.898	6
	Performance PS	-0.355	0.490	6
	Performance PM	0.852	0.067	5
Skeletal Muscle Mass (kg)	Performance SS	-0.061	0.909	6
	Performance PS	0.011	0.984	6
	Performance PM	0.445	0.453	5
Body Water (l)	Performance SS	-0.045	0.933	6
	Performance PS	0.005	0.993	6
	Performance PM	0.485	0.408	5

**. The correlation is significant at the 0,01 level (2 extremities).

*. The correlation is significant at the 0,05 level (2 extremities).

Table 9. Pearson Correlation and Significance Values for Female Athletes (Continuation).

Female		**Pearson Correlation**	**Sig (2 Extremities)**	N
ECW/TBW	Performance SS	0.222	0.672	6
	Performance PS	-0.154	0.771	6
	Performance PM	0.827	0.084	5
Right Arm Lean Mass (kg)	Performance SS	-0.113	0.832	6
	Performance PH	-0.039	0.942	6
	Performance PM	0-473	0.421	5
Left Arm Lean Mass (kg)	Performance SS	-0.101	0.849	6
	Performance PS	-0.053	0.921	6
	Performance PM	0.528	0.631	5
Right Leg Lean Mass (kg)	Performance SS	0.038	0.942	6
	Performance PS	-0.004	0.994	6
	Performance PM	0.597	0.288	5
Left Leg Lean Mass (kg)	Performance SS	0.019	0.971	6
	Performance PS	-0.025	0.963	6
	Performance PM	0.590	0.295	5
Trunk Lean Mass (kg)	Performance SS	-0.087	0.870	6
	Performance PS	-0.071	0.894	6
	Performance PM	0.572	0.314	5
Performance SS (Points/Nº Tournaments)	Performance SS	1		10
	Performance PS	0.779**	0.008	10
	Performance PM	0.343	0.366	9
Performance PS (Points/Nº Tournaments)	Performance SS	0.779**	0.008	10
	Performance PS	1		10
	Performance PM	-0.142	0.716	9
Performance PM (Points/Nº Tournaments)	Performance SS	0.343	0.366	9
	Performance PS	-0.142	0.716	9
	Performance PM	1		9

**. The correlation is significant at the 0,01 level (2 extremities).

*. The correlation is significant at the 0,05 level (2 extremities).

Table 10. Pearson Correlation and Significance Values for Whole Sample.

Both Genders		Pearson Correlation	Sig (2 Extremities)	N
Lower Limb Power (m)	Performance S	-0.279	0.198	23
	Performance P	-0.276	0.202	23
	Performance PM	0.180	0.447	20
Upper Limb Power (m)	Performance S	-0.243	0.264	23
	Performance P	-0.116	0.599	23
	Performance PM	0.322	0.167	20
Agility (sec)	Performance S	0.022	0.919	23
	Performance P	0.016	0.943	23
	Performance PM	-0.149	0.532	23
Height (m)	Performance S	-0.136	0.537	23
	Performance P	-0.061	0.783	23
	Performance PM	0.341	0.141	20
Body Mass (kg)	Performance S	-0.081	0.934	23
	Performance P	-0.066	0.766	23
	Performance PM	0.239	0.310	20
Body Mass Index (kg^{m2})	Performance S	0.018	0.934	23
	Performance P	-0.019	0.931	23
	Performance PM	-0.011	0.962	20
Skeletal Muscle Mass (kg)	Performance S	-0.245	0.421	13
	Performance P	-0.125	0.683	13
	Performance PM	0.677*	0.016	12

**. The correlation is significant at the 0,01 level (2 extremities).

*. The correlation is significant at the 0,05 level (2 extremities).

Table 10. Pearson Correlation and Significance Values for Whole Sample (Continuation).

Both Genders		Pearson Correlation	Sig (2 Extremities)	N
Body Water (l)	Performance S	-0.230	0.449	13
	Performance P	-0.111	0.719	13
	Performance PM	0.689*	0.013	12
ECW/TBW	Performance S	0.347	0.245	13
	Performance P	0.273	0.367	13
	Performance PM	-0.110	0.734	12
Right Arm Lean Mass (kg)	Performance S	-0.248	0.414	13
	Performance P	-0.097	0.753	13
	Performance PM	0.637*	0.026	12
Left Arm Lean Mass (kg)	Performance S	0.217	0.476	13
	Performance P	-0.071	0.817	13
	Performance PM	0.666*	0.018	12
Right Leg Lean Mass (kg)	Performance S	-0.155	0.614	13
	Performance P	-0.090	0.770	13
	Performance PM	0.765**	0.004	12
Left Leg Lean Mass (kg)	Performance S	-0.159	0.603	13
	Performance P	-0.083	0.786	13
	Performance PM	0.772**	0.003	12
Trunk Lean Mass (kg)	Performance S	-0.218	0.474	13
	Performance P	-0.081	0.793	13
	Performance PM	0.690*	0.013	12

**. The correlation is significant at the 0,01 level (2 extremities).

*. The correlation is significant at the 0,05 level (2 extremities).

Regarding male athletes, we can see that based on our results there is a significant correlation between the performance of Men's Singles (SH) and the performance of Men's Doubles (PH). No other significant correlations were found in our male sample.

Similarly to male athletes, there is a significant correlation between the performance of Woman's Singles (SS) and the performance of Woman's Doubles (PS). Additionally, a negative correlation was found between lower limb power and the performance of Mixed Doubles (PM).

When analysing the results of the joint analysis (not split by gender), SMM, body water, right arm lean mass, left arm lean mass, right leg lean mass, left leg lean mass and trunk lean mass all have a significant correlation with the performance of Mixed Doubles (PM). Even though we could not find any additional significant correlations, we could see that several analyses resulted in correlation coefficients equal or above 0.5 which is considered to be a large effect size (111). However, some of these results didn't achieve significance (p value < 0.05) and therefore could not be considered significantly associated.

Based on this rationale, some results, such as the correlation between right and left leg lean mass with mixed doubles performance in male athletes, are considered borderline (r= 0.741 and 0.741, p value = 0.057 and 0.057, respectively), nearly achieving significance and having a large effect size.

There also appears to be a borderline correlation between upper limb power and mixed doubles performance in male athletes (r= 0.573, p value = 0.065).

Likewise, in the female analysis there were also borderline significant correlations. The association between ECW/TBW and the performance in mixed doubles is one of these borderline results (r= 0.827, p value= 0.084).

Two unexpected borderline correlations were also found, namely a negative association between cardiovascular endurance and mixed double performance (r= -0.641, p value = 0.063), and the positive association between BF and mixed doubles performance in female athletes (r= 0.852, p value = 0.067).

4.4 Discussion

The present study aimed at studying the association of different fitness markers with athlete's performance in the Portuguese National Badminton Team. To our knowledge, this is the first study to focus on this topic.

When analysing the results obtained in this study, the significant correlation between singles and doubles performance in both male and female athletes, can raise the hypothesis that more competence in singles may provide a performance increase in doubles and/or vice-versa. Due to the structure of the Portuguese badminton calendar competitions (which only allow athletes to participate at a maximum of two events per tournament), a hypothesis can be made that choosing to play singles and doubles may be the most adequate choice if the athlete's preference and primary goal is to improve performance in either event.

The negative significant correlation between the performance of mixed doubles and lower limb power, although unusual, can, potentially, be related to the nature of the mixed doubles event, where an argument could be made that other factors such as positioning and technical proficiency may prove to be more important to the performance of female athletes. The small sample size of this study may also play a role in these results. Further research needs to be conducted in order to draw valid conclusions.

The significant correlation between SMM, all segmental body composition markers (right arm lean mass, left arm lean mass, right leg lean mass, left leg lean mass, trunk lean mass) and mixed doubles in the joint analysis (not split by gender), may bring up an hypothesis that athletes with more SMM and more lean mass (distributed across their body) tend to have better performances in the event of mixed doubles. This conclusion may be related to the fact that both male and female athletes are analysed together because when separated by gender, the same conclusions are not verified. The same can be hypothesized for body water which is also correlated with the performance in mixed doubles in the joint analysis but not when split by gender. These hypothesizes warrant further research.

In regard to the borderline correlations, or analysis which had a large effect size but did not achieve significance, the association between upper limb power and mixed doubles performance in male athletes may be related to and influence the existent significant correlation between these markers in the joint analysis, despite the same not being verified in female athletes.

This makes sense because upper limb power has shown to be correlated with smash velocity (111). The smash is considered a crucial stroke in mixed doubles, especially for male athletes due to the nature of the event. Despite no literature being found regarding the correlation between performance in the mixed doubles event and ECW/TBW, some data has shown that lower levels of intracellular water tend to reduce performance (specifically, grip strength) in judo athletes (108). The results obtained in this study (although not a significant correlation), appear to be in line with this logic.

Lastly, regarding the negative association between cardiovascular endurance and mixed double performance and the positive association between BF and mixed doubles performance in female athletes, although unexpected, these results can potentially mean that a higher BF level and worse cardiovascular endurance are associated with better performance in the event. As mentioned previously, one likely explanation for these results may be related to the nature of the mixed doubles event and the role of the female, where it could be hypothesized that other factors such as technical proficiency and positioning could, perhaps, be more important to their performance.

Nevertheless, although not being significant correlations, we believe that considering the small sample size included in the present study, these borderline results may benefit from some attention and further research in future studies.

One main strength of this study is the use of a battery of tests, which is easily implemented into the field, being easy to use by coaches and athletes and providing meaningful data without the need of specific and expensive resources. Another strength of the current study was the focus on a sample of elite Portuguese badminton players of the Portuguese national team. Despite the sample being composed of elite athletes, by focusing on such a specific population implies working with a small sample, which may reduce the statistical power.

Unfortunately, the main limitation of this study is a malfunction that occurred with the InBody S10 device during the body composition assessment that took place during the 4th day of the intervention, which corrupted the data of the body composition markers for the athletes that were tested in that day, reducing even further the sample size.

4.5 Conclusions

The main takeaway from this study is the existence of a significant correlation between the performance of singles and doubles in both male and female athletes. Additionally, there was a negative significant correlation between lower limb power and mixed doubles performance in female athletes.

Other technical and tactical markers not included in this study, such as positioning in the court and technical proficiency, may be more determinant to the mixed doubles performance of female athletes. Meanwhile, in the joint analysis (not split by gender), SMM, body water and all the segmental body composition markers (right arm lean mass, left arm lean mass, right leg lean mass, left leg lean mass, trunk lean mass) appear to be the most important markers in the mixed doubles event. Several studied variables showed borderline results regarding the correlation with performance, which warrants further research.

In terms of practical implications that could be drawn from this study, it may be recommended that both male and female athletes that wish to improve their performance in the singles event, also play the doubles event and/or vice-versa. For female athletes who wish to improve their mixed doubles performance, it may be recommended that instead of focusing on increasing lower limb power, they should perhaps emphasize their training on other markers not analysed in this study which may prove to be more important towards reaching this goal. More research is warranted in order to support this statement. Overall, it may be advised that athletes should focus on increasing their SMM (across all segments) and their body water, to increase mixed doubles performance.

It may be recommended that future studies include a bigger sample of athletes in order to increase statistical power and aim at more meaningful conclusions for overall athletes. Accordingly, it may also be suggested that the sample includes non-elite athletes, so that other significant data can be extrapolated into player with different performance levels.

Chapter 5 – Conclusions

5.1 Strengths and Limitations

There are some strengths and limitations to this dissertation. First, by including a scoping review, we consider that the work done is replicable, but on the other hand it is not inferential, which means that data cannot be extrapolated to the general population. This scoping review had some more limitations such as the noticeable diversity in the tests used to assess each marker of physical fitness, which makes the comparison process harder. Another limitation detected was the lack of studies conducted in this line of research. A possible way to circumvent this would be to increase the search parameters as to include papers written in different languages such as Chinese per example. This may be important since Asian countries have many high-level badminton players and further meaningful research may have been conducted in their native languages. Finally, the lack of consistency and coherence in the available literature is also viewed as a limitation since a greater number of studies are needed in some markers in order to be able to draw reliable and consistent conclusions.

Regarding the characterization study and the correlation study, a limitation that can be appointed is the small sample size, although, despite the fact that the number of participants included is indeed small, this can also be viewed as a strength, because it does not refer to a sample but rather to a population because it includes the whole Portuguese national badminton team, which in terms means that it is representative of the Portuguese elite badminton players. The battery of test used is also considered a strength due to its ease of use by coaches and athletes on the field. It can provide meaningful information without requiring a big financial and material resources. Finally, the biggest limitation of these two studies was the occurrence of a malfunction involving the InBody S10 device during the body composition assessment that took place during the 4th day of the intervention. This malfunction corrupted the results of the body composition markers for the athletes that were assessed in that day, reducing the sample size.

5.2 Main Findings

The scoping review provided some perception regarding the state of the current literature concerning the assessment of fitness in badminton players. The key takeaways from this study were mainly related to the lack of literature regarding this topic. Some markers show a big absence of available literature, while others, despite having available research, showed a visible lack of consensus surrounding the tests used to assess such markers. This scarcity of literature, diversity of tests used, and lack of test standardization not only complicate the process of comparison but also make drawing valid conclusions hard as a result of the lack of consistency, coherence, and consensus. In practical terms it may also have implications as it may take away from the quality of work put out by coaches and high-level athletes to reach better results. Standardizing fitness testing and publishing cutoff values is valuable and relevant in practical terms as this may lead to the development of more methodologies that enhance the work of coaches and consequently the performance of badminton players. Regardless of the lack of evidence for choosing the best fitness tests for badminton players, we selected the battery of tests applied in chapter 3 tests based on ease of use, practicality, available literature and replicability.

The characterization study sought to publish reference values for elite Portuguese badminton players, regarding body composition, agility, cardiovascular endurance, and both upper and lower limb explosive power. The publication of such values wishes to fill in the existing gap of available literature regarding the reference values for these markers. This absence of data may negatively impact the training done by athletes and coaches towards increasing performance. In that sense, this study may contribute to a more scientific based approach to training of Portuguese athletes, while also giving more accessible tools to be applied in the field by athletes and coaches and get valuable data concerning their athletic performance. The reference values for the selected fitness tests of the elite Portuguese badminton players can be found in chapter 3 of the present dissertation.

Finally, the correlation study provides a more practical analysis of the association between different physical fitness markers and athletic performance in the Portuguese national badminton team. In practical terms, the main takeaways are the significant correlation between the performance in singles and doubles in both male and female athletes.

Athletes who play singles tend to have better performance on doubles and vice-versa. Another relevant finding regarding the mixed doubles event was the correlation of better performance with their overall SMM and body water. This may highlight an opportunity for improving players performance, but further evidence is needed before guidelines or recommendations can be made. Meanwhile, it seems that female athletes who wish to improve their performance in the mixed doubles event should not focus their training on lower limb power. Instead, it may be hypothesized that other markers of technical and tactical nature, which were not analysed in the present study, may be more relevant towards achieving this goal.

5.3 Recommendations for Future Research

Future studies should take into consideration the limitations found in the three studies of the present dissertation. Regarding the scoping review, our main suggestion would be to increase the search parameters as to include papers written in different languages. As several other countries have big investments made in the sport, it is possible that more meaningful research has been conducted in their native languages. Another suggestion would be to utilize different samples, namely, youth badminton players or even disabled badminton players, the last being a field undergoing a big increase in popularity and investigation in this area may be welcomed.

Regarding the cross-sectional studies, some recommendations are to be considered, particularly those related with the sample, not only in size, in order to increase statistical power, but also non-elite athletes, with the purpose of discovering if the relationship between the studied variables still applies in different levels of performance.

It would also be interesting to apply this same intervention in other countries national teams, namely, countries with much higher and much lower performance levels to compare the cutoff values obtained in Portuguese elite badminton players and see how the values fluctuate.

Lastly, it would be advisable to also use other markers not studied in the present dissertation. As this document focused mainly on physical fitness markers, others beyond this scope such as biomechanics, tactical and technical factors may prove to be of meaning to improve the performance of elite athletes.

The authors find it necessary that the quantity of scientific production in this area is vastly increased, as it would provide numerous benefits towards the improvement and development of the sport, and it would also facilitate the work of coaches and athletes.

References

1. Kwan M, Cheng CL, Tang WT, Rasmussen J. Measurement of badminton racket deflection during a stroke. Sports Eng. 2010;12(3):143–53.
2. Cabello Manrique D. Analysis of the characteristics of competitive badminton. Br J Sports Med. 2003;37(1):62–6.
3. Kroner K, Schmidt SA, Nielsen AB, Yde J, Jakobsen BW, Moller-Madsen B, et al. Badminton injuries. Br J Sports Med. 1990;24(3):169–72.
4. Patterson S, Pattison J, Legg H, Gibson AM, Brown N. The impact of badminton on health markers in untrained females. J Sports Sci. 2017;35(11):1098– 106.
5. Cabello-Manrique D, Lorente JA, Padial-Ruz R, Puga-González E. Play Badminton Forever: A Systematic Review of Health Benefits. Int J Environ Res Public Health. 2022;19(15):9077.
6. Dewney J, Brodie D. Get Fit for Badminton. London: Pelham; 1980.
7. Lei RR, Deng SX, Lu LF. Study on the physiological function, physical quality and mental characteristics of the Chinese badminton players. Chin Sport Sci Technol. 1993;(29):28 38.
8. PORDATA. Praticantes desportivos federados: total e por todas as federações desportivas. 2021. Available at: https://www.pordata.pt/Portugal/Praticantes+desportivos+federados+total+e+por+todas+as+federa%C3%A7%C3%B5es+desportivas-2227
9. Federação Portuguesa Badminton. Organização Competitiva - Normas Orientadoras. 2011. Available at: https://www.fpbadminton.pt/Organizacao%20Competitiva%20-%20Normas%20orientadoras%20-%202011-2012.PDF
10. Federação Portuguesa Badminton. Regulamento Técnico. 2007. Available at: https://www.fpbadminton.pt/Regulamento%20Tecnico%20-%2030%20Junho%202007.PDF
11. Federação Portuguesa Badminton. Sistema Competitivo de Séniores 2023. Available at: https://fpbadminton.pt/wp-content/uploads/Sistema-Competitivo-Seniores-2023.pdf
12. Caspersen CJ, Powell KE, Christenson GM. Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. Public Health Rep. 1985;100(2):126–31.
13. Liguori, G., Feito, Y., Fountaine, C. (Charles J., & Roy, B. (Eds.). ACSM's Guidelines for Exercise Testing and Prescription. Eleventh edition., Wolters Kluwer, 2021.

14. Britton Ú, Issartel J, Fahey G, Conyngham G, Belton S. What is health-related fitness? Investigating the underlying factor structure of fitness in youth. Eur Phys Educ Rev. 2020;26(4):782–96.
15. DeMet T, Wahl-Alexander Z. Integrating Skill-Related Components of Fitness into Physical Education. Strategies. 2019;32(5):10–7.
16. Malina RM. Physical activity and fitness: Pathways from childhood to adulthood. Am J Hum Biol. 2001;13(2):162–72.
17. Cinthuja P. Physical fitness factors of school badminton players in Kandy district. 2015;
18. Ismail MSH, Boon Suen A, Othman CN. Comparison of anthropometric variables and leg strength of volleyball, basketball and badminton players. Malays J Med Lab Sci. 1993;10(1):26–30.
19. Singh J, Raza S, Mohammad A. Physical Characteristics and Level of Performance in Badminton: A Relationship Study. J Educ Pract. 2011;2(5).
20. Sheppard JM, Young WB. Agility literature review: Classifications, training and testing. J Sports Sci. 2006;24(9):919–32.
21. Irawan D. Six Weeks Progressive Plyometrics Training on Badminton Player's Agility. Em: Proceedings of the Health Science International Conference (HSIC 2017) [Internet]. Malang, Indonesia: Atlantis Press; 2017.
22. Malina RM. Body Composition in Athletes: Assessment and Estimated Fatness. Clin Sports Med. 2007;26(1):37–68.
23. Pion J, Segers V, Fransen J, Debuyck G, Deprez D, Haerens L, et al. Generic anthropometric and performance characteristics among elite adolescent boys in nine different sports. Eur J Sport Sci. 2015;15(5):357–66.
24. Högström GM, Pietilä T, Nordström P, Nordström A. Body Composition and Performance: Influence of Sport and Gender Among Adolescents. J Strength Cond Res. 2012;26(7):1799–804.
25. Akdogan E, Kanat EA, Simsek D, Cerrah AO, Bidil S, Bayram I, et al. Relationship Between Body Composition, Multiple Repeated Sprint Ability and Vertical Jump Performance in Elite Badminton Players. Int J Morphol. 2022;40(3):720– 7.
26. Lord SR, Sherrington C, Menz HB. Falls in older people: risk factors and strategies for prevention. Cambridge: Cambridge University Press; 2001. 249 p.
27. Malwanage KT, Senadheera VV, Dassanayake TL. Effect of balance training on footwork performance in badminton: An interventional study. Abián-Vicén J, editor. PLOS ONE. 2022;17(11):e0277775.

28. Zulhidayah Y. Relationship of Nutritional Status Toward Cardiovascular Resistance of Badminton Players. Proceeding of The International Conference on Science and Advanced Technology (ICSAT). 2021.
29. Zajac FE. Muscle coordination of movement: A perspective. J Biomech. 1993;26:109–24.
30. Robertson K, Pion J, Mostaert M, Norjali Wazir MRW, Kramer T, Faber IR, et al. A coaches' perspective on the contribution of anthropometry, physical performance, and motor coordination in racquet sports. J Sports Sci. 2018;36(23):2706–15.
31. MAHULKAR, Shrikant S. Relationship of strength and flexibility with skill performance in badminton players. International journal of physical education, sports and health, 2016, 3.5: 38-40.
32. Tuan TM, Son NDM, Hanh LTM. BUILDING UP THE 12-WORK-OUTS TO IMPROVE THE MUSCULAR ENDURANCE FOR MALE BADMINTON TEAM. Eur J Phys Educ Sport Sci. 2022
33. Bańkosz, Ziemowit & Nawara, Henryk & Ociepa, Marcin. (2013). Assessment of simple reaction time in badminton players. TRENDS in Sport Sciences. 2013. 54-61.
34. Dube S, Mungal S, Kulkarni M. Simple visual reaction time in badminton players: A comparative study. Natl J Physiol Pharm Pharmacol. 2015;5(1):18.
35. Sonoda T, Tashiro Y, Suzuki Y, Kajiwara Y, Zeidan H, Yokota Y, et al. Relationship between agility and lower limb muscle strength, targeting university badminton players. J Phys Ther Sci. 2018;30(2):320–3.
36. Ahmed S, Saraswat A, Esht V. Correlation of core stability with balance, agility and upper limb power in badminton players: a cross-sectional study. Sport Sci Health. 2022;18(1):165–9.
37. Corbin CB, Lindsey R. Fitness for life. Updated 5th ed. Champaign, IL: Human Kinetics; 2007. 327 p.
38. Campos FA, Daros LB, Matrascusa VL, Dourado AC, Stanganelli LR. ANTHROPOMETRIC PROFILE AND MOTOR PERFORMANCE OF JUNIOR BADMINTON. Braz J Biomotricity. 2009;3(2):146–51.
39. Muller E, Benko U, Raschner C, Schwameder H. Specific fitness training and testing in competitive sports: Med Sci Sports Exerc. 2000;216.
40. Phomsoupha M, Laffaye G. The Science of Badminton: Game Characteristics, Anthropometry, Physiology, Visual Fitness and Biomechanics. Sports Med. 2015;45(4):473–95.
41. Chin MK, Wong AS, So RC, Siu OT, Steininger K, Lo DT. Sport specific fitness testing of elite badminton players. Br J Sports Med. 1995;29(3):153–7.

42. Fukuda DH. Assessments for sport and athletic performance. Champaign, IL: Human Kinetics; 2019.
43. Mancha-Triguero D, García-Rubio J, Calleja-González J, Ibáñez SJ. Physical fitness in basketball players: a systematic review. J Sports Med Phys Fitness [Internet]. 2019.
44. Koopmann T, Faber I, Baker J, Schorer J. Assessing Technical Skills in Talented Youth Athletes: A Systematic Review. Sports Med. 2020;50(9):1593– 611.
45. Haff G, Triplett NT, National Strength & Conditioning Association (U.S.), editores. Essentials of strength training and conditioning. Fourth edition. Champaign, IL: Human Kinetics; 2016. 735 p.
46. Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D, et al. PRISMA Extension for Scoping Reviews (PRISMA-ScR): Checklist and Explanation. Ann Intern Med. 2018;169(7):467–73.
47. Ouzzani M, Hammady H, Fedorowicz Z, Elmagarmid A. Rayyan—a web and mobile app for systematic reviews. Syst Rev. 2016;5(1):210.
48. Rosenzweig R. Zotero [Internet]. Centre for History and New Media.; 2016. Available at: www.zotero.org/download
49. Abián P, Coso JD, Salinero JJ, Gallo-Salazar C, Areces F, Ruiz-Vicente D, et al. Muscle damage produced during a simulated badminton match in competitive male players. Res Sports Med. 2016;24(1):104–17.
50. Dong M, Lyu J, Hart T, Zhu Q. Should agility training for novice badminton players be physically or perceptually challenging? J Sports Med Phys Fitness. 2020; 59(12).
51. Fernandez-Fernandez J, Loturco I, Hernández-Davó J, Nakamura F, García-Tormo V, Álvarez-Dacal F, et al. On-Court Change of Direction Test: An Effective Approach to Assess COD Performance in Badminton Players. J Hum Kinet. 2022; 82:155–64.
52. Guo Z, Huang Y, Zhou Z, Leng B, Gong W, Cui Y, et al. The Effect of 6-Week Combined Balance and Plyometric Training on Change of Direction Performance of Elite Badminton Players. Front Psychol. 2021; 12:684964.
53. Loureiro L de FB, de Freitas PB. Development of an Agility Test for Badminton Players and Assessment of Its Validity and Test–Retest Reliability. Int J Sports Physiol Perform.11(3):305–10.
54. Lu Z, Zhou L, Gong W, Chuang S, Wang S, Guo Z, et al. The Effect of 6-Week Combined Balance and Plyometric Training on Dynamic Balance and Quickness Performance of Elite Badminton Players. Int J Environ Res Public Health. 2022;19(3):1605.
55. Molaeikhaletabadi M, Bagheri R, Hemmatinafar M, Nemati J, Wong A, Nordvall M, et al. Short-Term Effects of Low-Fat Chocolate Milk on Delayed Onset Muscle Soreness and Performance in Players on a Women's University Badminton Team.

Int J Environ Res Public Health. 2022;19(6):3677.

56. Panda M, Rizvi MR, Sharma A, Sethi P, Ahmad I, Kumari S. Effect of electromyostimulation and plyometrics training on sports-specific parameters in badminton players. Sports Med Health Sci. 2022;4(4):280–6.
57. Phomsoupha M, Berger Q, Laffaye G. Multiple Repeated Sprint Ability Test for Badminton Players Involving Four Changes of Direction: Validity and Reliability (Part 1). J Strength Cond Res. 2018;32(2):423–31.
58. Phomsoupha M, Laffaye G. Multiple Repeated-Sprint Ability Test With Four Changes of Direction for Badminton Players (Part 2): Predicting Skill Level With Anthropometry, Strength, Shuttlecock, and Displacement Velocity. J Strength Cond Res. 2020;34(1):203–11.
59. Tomaszewski P, Kęska A, Tkaczyk J, Nowicki D, Sienkiewicz-Dianzenza E. Somatic characteristics and motor fitness of elite and sub-elit.pdf. J Sports Med Phys Fitness. 2018;58(10):1456–64.
60. Zhao W, Wang C, Bi Y, Chen L. Effect of Integrative Neuromuscular Training for Injury Prevention and Sports Performance of Female Badminton Players. Hsieh TH, editor. BioMed Res Int. 2021:1–12.
61. Alikhani R, Shahrjerdi S, Golpaigany M, Kazemi M. The effect of a six-week plyometric training on dynamic balance and knee proprioception in female badminton players. J Can Chiropr Assoc. 2019;63(3):144–53.
62. Zhou L, Gong W, Wang S, Guo Z, Liu M, Chuang S, et al. Combined balance and plyometric training enhances knee function, but not proprioception of elite male badminton players: A pilot randomized controlled study. Front Psychol. 2022; 13:947877.
63. Awatani T, Morikita I, Urata T, Shinohara J, Tatsumi Y. Correlation between isometric shoulder strength and racket velocity during badminton forehand smash movements: study of valid clinical assessment methods. J Phys Ther Sci. 2018;30(6):850–4.
64. Bottoms L, Sinclair J, Taylor K, Polman R, Fewtrell D. The effects of carbohydrate ingestion on the badminton serve after fatiguing exercise. J Sports Sci. 2012;30(3):285–93.
65. Erdoğan AT, Umutlu G, Acar NE. Evaluation of shoulder strength characteristics in overhead sports and range of motion related changes during isokinetic testing. Isokinet Exerc Sci. 2019;27(2):153–61.
66. Ferreira A, Górski M, Gajewski J. Gender differences and relationships between upper extremity muscle strength, lower limb power and shuttle velocity in forehand smash and jump smash in badminton. Acta Bioeng Biomech. 2020;22(4):41–9.

67. Madsen CM, Karlsen A, Nybo L. Novel Speed Test for Evaluation of Badminton-Specific Movements. J Strength Cond Res. 2015;29(5):1203–10.
68. Narang S, Patil D. Determination of Ballistic Six Exercises and Theraband Exercises on Physical Performance in Badminton Players: A Randomized Controlled Clinical Trial. J Pharm Res Int. 2021;281–91.
69. Santos AMS, Maldonado AJ, de Sousa Junior AVM, Brito SOS, de Moura RC, Figueiredo C, et al. Brain-Derived Neurotrophic Factor and Psychophysiological Response in Youth Badminton Athletes During the Season. Int J Sports Physiol Perform. 2022;17(2):296–306.
70. Schmidt SV, Engelhardt JA, Cools A, Magnusson SP, Couppé C. Acromio-Humeral Distance Is Associated with Shoulder External Strength in National Elite Badminton Players—A Preliminary Study. Sports. 2021;9(4):48.
71. van de Water T, Huijgen B, Faber I, Elferink-Gemser M. Assessing Cognitive Performance in Badminton Players: A Reproducibility and Validity Study. J Hum Kinet. 2017;55(1):149–59.
72. Ng GYF, Lam PCW. A Study of Antagonist/Agonist Isokinetic Work Ratios of Shoulder Rotators in Men Who Play Badminton. J Orthop Sports Phys Ther. 2002;32(8):399–404.
73. Rusdiana, Agus. Analysis Differences of Vo2max between Direct and Indirect Measurement in Badminton, Cycling and Rowing. Journal of Applied Physiology. 2020;9. 2322-3537.
74. Tillman MD, Hass CJ, Brunt D, Bennett GR. Jumping and landing techniques in elite women's volleyball. J Sports Sci Med. 2004;3(1):30–6.
75. Kale M, Aşçi A, Bayrak C, Açikada C. Relationships Among Jumping Performances and Sprint Parameters During Maximum Speed Phase in Sprinters. J Strength Cond Res. 2009;23(8):2272–9.
76. Requena B, González-Badillo JJ, Villareal ESSD, Ereline J, García I, Gapeyeva H, et al. Functional Performance, Maximal Strength, and Power Characteristics in Isometric and Dynamic Actions of Lower Extremities in Soccer Players. J Strength Cond Res. 2009;23(5):1391–401.
77. Wilkinson M, Leedale-Brown D, Winter EM. Reproducibility of Physiological and Performance Measures from a Squash-Specific Fitness Test. Int J Sports Physiol Perform. 2009;4(1):41–53.
78. Lees A, Cabello D, Torres G. Science and racket sports IV. Pbk. ed. London: Routledge; 2011.
79. Wilkinson M, Leedale-Brown D, Winter EM. Validity of a Squash-Specific Test of Change-of-Direction Speed. Int J Sports Physiol Perform. 2009;4(2):176– 85.

80. Siddiqa A, Amjad S, Tabassum Y, Butt MZI. Comparison of handgrip strength between right-hand and left-hand university male badminton players. 2024;
81. Panda M, Rizvi MR, Sharma A, Sethi P, Ahmad I, Kumari S. Effect of electromyostimulation and plyometrics training on sports-specific parameters in badminton players. Sports Med Health Sci. 2022;4(4):280–6.
82. Alikhani R, Shahrjerdi S, Golpaigany M, Kazemi M. The effect of a six-week plyometric training on dynamic balance and knee proprioception in female badminton players. 2019;
83. Europe C of. Eurofit: Handbook for the EUROFIT tests of physical fitness. Rome: Secretariat of the Committee for the Development of Sport within the Council of Europe.; 1987.
84. Matthys W, Vanderschuren LJMJ, Schutter DJLG. The neurobiology of oppositional defiant disorder and conduct disorder: Altered functioning in three mental domains. Dev Psychopathol. 2013;25(1):193–207.
85. Bruininks RH, Bruininks BD. Bruininks-Oseretsky Test of Motor Proficiency, Second Edition (BOT-2). APA PsycTests . 2.nd edition. 2005;
86. Hamilton A, Balnave R, Adams R. Grip Strength Testing Reliability. J Hand Ther. 1994;7(3):163–70.
87. Sturgess S, Newton RU. Design and Implementation of a Specific Strength Program for Badminton. Strength Cond J. 2008;30(3):33–41.
88. Nadzalan AM, Mohamad NI, Lee JLF, Chinnasee C. Relationship between muscle architecture and badminton-specific physical abilities. Hum Mov. 2018;2018(1):44– 50.
89. Guan X, Li Y, Bai Y. Special Physical Characteristic and Training Strategy of Badminton Based on Machine Learning Algorithm. Int Trans Electr Energy Syst.; 2023:1–1.
90. Krizkova S, Tomaskova H, Tirkolaee EB. Sport Performance Analysis with a Focus on Racket Sports: A Review. Appl Sci. 2021;11(19):9212.
91. Butterworth DA, Turner JD, Johnstone AJ. Coaches' perceptions of the potential use of performance analysis in badminton. Int J Perform Anal Sport. 2012;12(2):452–67.
92. Rana MMS. ASSESSMENT OF PHYSIOLOGICAL VARIABLES OF BADMINTON PLAYERS. 2012;
93. Yadav SK. Relationship of selected motor fitness variables with the performance of badminton players. Int J Phys Educ Sports Health. 2017;
94. Lohman TG, Roche AF, Martorell R, editores. Anthropometric standardization reference manual. Champaign, IL: Human Kinetics Books; 1988. 177 p.
95. NIHR Southampton. Procedure for measuring adult height [Internet]. 2016. Available at: https://www.uhs.nhs.uk/Media/Southampton-Clinical-Research/Procedures/BRCProcedures/Procedure-for-adult-height.pdf

96. Norton K, editor. Anthropometrica: a textbook of body measurement for sports and health courses. Repr. Sydney, NSW: UNSW Press; 2002. 420 p.
97. Harris C, Wattles AP, Debeliso M, Sevene-Adams PG, Berning JM, Adams KJ. The seated medicine ball throw as a test of upper body power in older adults. 2011;
98. Manoj T, Arun NC. The seated medicine ball throw as a test of upper body strength in undergraduate students. 2020; 5. 1-04.
99. Beckham G, Lish S, Disney C, Keebler L, DeBeliso M, Adams KJ. The Reliability of the Seated Medicine Ball Throw as Assessed with Accelerometer Instrumentation. J Phys Act Res.
100. Rahman ZA. Reliability, Validity, and Norm References of Standing Broad Jump. Rev Gest Inov E Tecnol. 2021;11(3):1340–54.
101. Ooi CH, Tan A, Ahmad A, Kwong KW, Sompong R, Mohd Ghazali KA, et al. Physiological characteristics of elite and sub-elite badminton players. J Sports Sci. 2009;27(14):1591–9.
102. Bishop D. Warm Up I: Potential Mechanisms and the Effects of Passive Warm Up on Exercise Performance. Sports Med. 2003;33(6):439–54.
103. Silva LM, Neiva HP, Marques MC, Izquierdo M, Marinho DA. Effects of Warm-Up, Post-Warm-Up, and Re-Warm-Up Strategies on Explosive Efforts in Team Sports: A Systematic Review. Sports Med. 2018;48(10):2285–99.
104. Abián P, Abián-Vicén J, Sampedro J. Análisis Antropométrico de la Simetría Corporal en Jugadores de Bádminton. Int J Morphol. 2012;30(3):945– 51.
105. Abián P, Simón-Chico L, Bravo-Sánchez A, Abián-Vicén J. Elite Badminton Is Getting Older: Ages of the Top 100 Ranked Badminton Players from 1994 to 2020. Int J Environ Res Public Health. 10 de novembro de 2021;18(22):11779.
106. Santos NM. Caracterização cineantropométrica, composição corporal e capacidade bio-motora do jogador de Badminton de Elite Nacional. [Tese de Mestrado para obtenção do grau de Mestre em Treino Desportivo para Crianças e Jovens.]. [Coimbra, Portugal]: Universidade de Coimbra; 2018.
107. Silva AM, Fields DA, Heymsfield SB, Sardinha LB. Relationship Between Changes in Total-Body Water and Fluid Distribution With Maximal Forearm Strength in Elite Judo Athletes. J Strength Cond Res. setembro de 2011;25(9):2488–95.
108. Vaziri B, Dabadghao S, Yih Y, Morin TL. Properties of sports ranking methods. J Oper Res Soc. 4 de maio de 2018;69(5):776–87.
109. Trewin CB, Hopkins WG, Pyne DB. Relationship between world-ranking and Olympic performance of swimmers. J Sports Sci. abril de 2004;22(4):339–45.

110. Cohen J, Cohen P, West SG, Aiken LS. Applied Multiple Regression/Correlation Analysis for the Behavioral Sciences [Internet]. 2nd Edition. 1983. 545 p. Disponível em: https://www.taylorfrancis.com/books/mono/10.4324/9780203774441/applied-multiple-regression-correlation-analysis-behavioral-sciences-jacob-cohen-patricia-cohen-stephen-west-leona-aiken

111. Indora NK, Anand P, Chettri S, Kumar V. Correlation of Upper Limb Explosive Power with Smash Velocity and Performance in Badminton Players: A Cross-sectional Study. J Clin Diagn Res [Internet]. 2022 [citado 19 de junho de 2024]; Disponível em: https://www.jcdr.net//article_fulltext.asp?issn=0973-709x&year=2022&month=May&volume=16&issue=5&page=YC09-YC11&id=16381

112. Macedo, L. S., & Verli, M. V. A. (2023). A historical recovery of badminton: from Asia to Brazil. Revista Eletrônica Interdisciplinar, 15(2), 26-37.

Annexes

Annex 1. Agility Table.

Agility						
Article/ Reference	**Goal of the Study**	**Sample**	**Intervention**	**Methods / Agility Measuring Protocol**	**Results of Interest/ Cutoff Values**	**Main Conclusions**
(60)	To Investigate the effects of Integrated Neuromuscular Training (INT) on injury prevention and the performance of professional female badminton athletes.	n= 38 elite male badminton athletes: High-Risk Group (HG) = 22 Low-Risk Group (LG)= 16.	8-week INT program consisting of four 90-min sessions/week. Movement asymmetries, physical fitness, and special abilities were tested before and after the intervention.	Standard Arrowhead Agility Test (SAT) (ability to accelerate, decelerate, and change direction while running).	SAT (sec): HG Pre: 17:39±0:57 HG Post: 17:04±0:63 LG Pre: 17:07±0:62 LG Post: 16:8±0:60	INT can effectively improve the limbs' asymmetry of female badminton athletes, prevent sports injury, and improve the athlete's performance. Athletes in different risk groups showed differences in the degree of motor skills' improvement.
(54)	To investigate the effects of combined balance and Plyometric (PT) training on dynamic balance and quickness performance of elite badminton athletes.	n= 16 elite male badminton athletes: Balance-Plyometric (PB)= 8 Plyometric (PT)= 8	PB group took part in a balance combined with PT training and PT group took part in PT-only training for 6 weeks. The dynamic stability and quick movement ability were assessed at baseline and after the intervention.	Modified T-Test (researchers adjusted the distance to fit the badminton court specificity). Hexagon Test (standard hexagon test was applied to assess COD ability for badminton and was verified as an effective method to evaluate the on-court performance of players).	Modified T-Test (sec): PB Pre: 7.38±0.19 PB Post: 6.77±0.11 PT Pre: 7.39±0.24 PT Post: 6.96±0.13 Hexagon Test (sec): PB Pre: 3.83±0.32 PB Post: 2.95±0.14 PT Pre: 3.95±0.29 PT Post: 3.25±0.33	Balance training combined with PT training can strengthen dynamic balance ability and improve the quickness performance of male elite badminton players. Balance training combined with PT training was considered to wield superior results in comparison to PT training.

Annex 1. Agility Table (Continuation).

Agility						
Article/ Reference	**Goal of the Study**	**Sample**	**Intervention**	**Methods / Agility Measuring Protocol**	**Results of Interest/ Cutoff Values**	**Main Conclusions**
(52)	To investigate the effect of combined balance and PT training on the COD performance of badminton athletes.	n=16 elite male badminton athletes PB= 8 PT= 8	PB group took part in a balance combined with PT training and PT group took part in PT-only training for 6 weeks. Athletes were tested to assess the COD ability before and after the training period.	Modified Standard Southeast Missouri (SEMO) Test (the test area was set up on a badminton half-court with a length of 6.70 m and a width of 6.10 m to fit the badminton specificity). Modified 5-0-5 COD Test (the running distance was adjusted to fit the badminton court specificity).	Modified SEMO Test (sec): PB Pre: 13.38±0.45 PB Post: 12.78±0.31 PL Pre: 13.37±0.37 PL Post: 13.06±0.38 Modified 5-0-5 COD Test (sec): PB Pre: 3.76±0.25 PB Post: 3.44±0.15 PL Pre: 3.72±0.16 PL Post: 3.62±0.17	Combined training induced an overall better adaptation for the SEMO TEST, the 5-0-5 COD test, the YBT, and the Reactive Strength Index (RSI) test than PT training. Considering that balance training is relatively time-efficient (20 min in the current study), it is suggested that adding such exercises would allow optimal training adaptations for badminton players.
(55)	To investigate the short-term effects of low-fat chocolate milk consumption on delayed onset muscle soreness (DOMS) and performance in female badminton players.	n= 7 female badminton players Low Fat Chocolate Milk Group (LFCM)= 4 Placebo Group = 3 After one week, the individuals switched groups.	Participants were randomly assigned to 1 week of LFCM (500 mL) or placebo (water, 500 mL) consumption in a crossover design. LFCM or water was consumed immediately after each training session. Performance variables were assessed pre- and post-intervention.	The SEMO test was used for agility assessment.	Pre-Test Baseline (sec): 14.8±1.1 Post Test LFCM (sec): 14.2±0.38 Post Test Placebo (sec): 14.3±0.35	There were no significant changes in maximum anaerobic power, agility, and maximum handgrip strength. LFCM, as a post-exercise beverage, may help speed recovery in female badminton players but has no effect on agility performance.
(59)	To assess somatic build and physical fitness of elite and sub-elite Polish badminton players and to identify key traits that determine achieving sporting success in badminton.	n= 20 men from the Polish National Badminton Teams A and B: Elite (A) = 9 Sub-Elite (B) = 11	Participants underwent anthropometric assessment and fitness testing, including two badminton-specific on-court movement tests, and a cycloergometer test (Vo2 Max).	SAT: Participant shuffled laterally across the width of the court for a total of 10 repetitions. Starting from the central base, the participant struck the up-turned shuttlecocks placed in sectors A and B of the court using his dominant hand (one shuttlecock at a time), returning to the central base after each strike (right-handed participant began striking the shuttlecocks from the right side, and left-handed players began from the left side). 4 Corner Agility Test: Very similar to the SAT with the exception that the 4 up-turned shuttlecocks were placed at each corner of the court.	SAT (sec): A = 16.2±0.5 B = 16.1±0.3 4 Corner Agility Test (sec): A = 30.6±1.9 B = 29.7±1.1	Relatively small body size of badminton players can be considered advantageous in sport competitions. Aerobic capacity contributes to achieving sport success in badminton to a much lower degree than the badminton-specific on-court skills.

Annex 1. Agility Table (Continuation).

Agility						
Article/ Reference	**Goal of the Study**	**Sample**	**Intervention**	**Methods / Agility Measuring Protocol**	**Results of Interest/ Cutoff Values**	**Main Conclusions**
(23)	To investigate whether the test items used in the FSC can differentiate athletes in nine sports (badminton, basketball, gymnastics, handball, judo, soccer, table tennis, triathlon, and volleyball).	n= 141 elite young male athletes (16.1±0.8 years) Badminton = 12.	Participants completed the 22 tests of the FSC, consisting of anthropometric, physical performance and motor coordination measurements.	Agility was assessed by a 10 × 5 m SR test (Council of Europe, 1988).	Badminton (sec) = 17.634±0.604	Elite adolescent boys show differences in generic characteristic, as assessed by the FSC tests, according to their specific sport. FSC tests also identified relevant characteristics for each sport, which could be used in the purposeful orientation of individuals according to their strengths and their weaknesses for different sports.
(81)	To compare the effects of four weeks of PT training and EMS of knee extensor and ankle plantar flexor muscles on agility, 30-m sprint, lower limb explosive power and jumping ability amongst badminton players.	State level badminton players (n= 90): PT= 30. EMS group (EG= 30). Control Group (CG)= 30.	Pre-Post test Design with PG, Electromyostimulation (EMS) group and CG. was used. PT training was carried out 2x/week, and EMS was carried out 4x/week for four weeks. CG did not receive any intervention. All three groups continued their usual badminton training throughout the study. Players were assessed for agility, 30-m sprint, SBJ, and Vertical Jump Height (VJH).	A Standard agility t-test was used to measure agility. Four cones were placed in a standard manner. On command, each player started sprinting 10 m from cone A to touch the base of cone B, followed by shuffling 5 m towards the left side to touch the base of cone C, followed by shuffling 10-m towards the right side to touch the base of cone D, followed by shuffling 5-m to the left to touch the base of cone B and sprinting back to the cone A.	PT (sec) = 11.43±0.79 EMS Group (sec) = 10.99±0.57 CG (sec) = 11.99±0.81	PT training showed significant improvement in sprint time and jumping ability, whereas EMS training showed significant Improvement only in jumping ability.
(53)	To develop an agility test that simultaneously assesses perception and motor capacity and examine the test's concurrent and construct validity and its test–retest reliability	n = 43 Badminton players (29 male and 14 female)	The authors recruited 43 badminton players (17–32 y old) to evaluate concurrent (with shuttle-run agility test) and construct validity and test–retest reliability. The athletes performed the Badcamp test and the Shuttle Run Agility Test (SRAT) on the day 1 of a national tournament. First, they performed the Badcamp and 5 min later they performed the SRAT.	SRAT: The standard SRAT consists of running 5 m in a straight line and going back to start position 5 times. Badcamp: The Badcamp agility test consists of running as fast as possible to 6 targets placed on the corners and middle points of a rectangular area (5.6 × 4.2 m) from the start position located in the centre of it, following visual stimuli presented in a luminous panel.	Badcamp (sec) = 14.62±1.15 SRAT (sec) = 18.45±1.7	The findings indicate that Badcamp is an effective, valid, and reliable tool to measure agility, allowing coaches and athletic trainers to evaluate players' athletic condition and training effectiveness and possibly detect talented individuals in this sport.

Annex 1. Agility Table (Continuation).

Agility						
Article/ Reference	**Goal of the Study**	**Sample**	**Intervention**	**Methods / Agility Measuring Protocol**	**Results of Interest/ Cutoff Values**	**Main Conclusions**
(49)	To assess the occurrence of muscle damage after a simulated badminton match and its influence on physical and haematologic al parameters.	n = 16 Competitive male badminton players	Before and just after a 45-min simulated badminton match, maximal isometric force and badminton specific running/movement velocity were measured to assess muscle fatigue. Blood samples were also obtained before and after the match.	Adapted Footwork Test: Participants performed an adapted version of the footwork test by Chin et al. (1995) and it was executed in one half of a regular badminton court. Agility T-Test: The T-test was adapted from Pauole, Madole, Garhammer, Lacourse, and Rozenek (2000) Four 15-cm collapsible cones were arranged, while only one pair of photocells was placed at the start and finish line.	Adapted Footwork Test Pre (sec) = 21.0±1.7 Adapted Footwork Test Post (sec) = 20.9±1.8 Agility T-Test Pre (sec) = 10.1±0.4 Agility T-Test Post (sec) = 10.0±0.4	A simulated badminton match modified haematological parameters of whole blood and serum blood that indicate the occurrence of muscle fibre damage. However, the level of muscle damage did not produce decreased muscle performance.
(57)	To develop a new sport-specific, repeated-sprint ability test involving 4 changes of direction, namely, the Multiple Repeated Sprint Ability (MRSAB) test for badminton players, and to determine its validity by comparing the results of 5 different skill levels. It was also to assess the link between the new test and neuromuscul ar lower limb and physiological variables.	n = 42 badminton players ranging from novice to elite levels. Elite = 9 Highly Skilled = 9 Skilled = 9 Intermediate = 9 Novice = 6	The participants were separated into 5 groups to perform the MRSAB test at the same time of day, on 2 occasions, separated by at least 48 hours. The best time, mean time, and fatigue index were measured. Heart rate and blood lactate concentration were also recorded to determine the participants' physiological responses to the test.	The MRSAB test consisted of 2 repetitions of 4 movements (4 3 3 m) separated by 30 seconds of passive recovery. This pattern was repeated 10 times.	Mean Values: Best Time (sec): 16.5±2.2 Mean Time (sec): 18.1±2.8 Fatigue Index (%): 9.3±5.9	The results show that the MRSAB test is valid, because it differentiates between the 5 skill levels for best time, mean time and fatigue index and offers a reliable method for testing badminton players, with no differences between the sessions. Moreover, the link between mean time and neuromuscular variables, such as jump height in squats and countermovements and with _ VO2max reveals that this test uses a combination of the anaerobic and aerobic systems, thus, it can be used by trainers either to improve movement ability or increase these physical qualities.

Annex 1. Agility Table (Continuation).

Agility						
Article/ Reference	**Goal of the Study**	**Sample**	**Intervention**	**Methods / Agility Measuring Protocol**	**Results of Interest/ Cutoff Values**	**Main Conclusions**
(50)	To explore and compare SR with Reaction Initiation Training (RIT) to determine the relative effectiveness of these training methods on improving the on-court agility of badminton players.	n = 20 novice badminton players RIT = 10 SR = 10	20 novice badminton players were split in half to receive either RIT or SR on court for five days. Before and after training, the on-court agility test with and without anticipation was administered.	The on-court agility test involved intercepting a randomly thrown shuttlecock on a regular badminton court as quickly and accurately as possible. The centre line was marked by a small piece of blue tape 1.95m from the short service line, and the participant was asked to occupy the marked position with a racquet held in hand. A certified badminton coach stood behind the net on the other side of the court, throwing a shuttlecock from the centre of the net randomly to one of six corners of the player's court with varying direction and speed.	Not Specified	Both training methods shortened the mean running time, however, only RIT additionally reduced the initiation time and its proportion on those time-consuming positions when agility was assessed without anticipation. Therefore, agility training for novice badminton players should be more perceptually than physically challenging to avoid vain effort and unnecessary injuries.
(51)	To assess the reliability of a specific COD test (i.e., "OnCourt COD test") in youth badminton players, evaluate the effect of age on On-Court COD performance, and examine its correlations with linear speed, COD speed, and VJ tests.	n = 42 young badminton players (27 males and 15 females) Under 17 = 21 Under 19 = 21	42 young badminton players were divided into two age groups and took part in assessment routines which took part in two different days. All tests were performed in the same order, using the same testing devices, measurement protocols, and experienced evaluators.	Traditional 505 COD Test: The 505 COD test requires players to sprint 5m, turn 180°, and sprint further 5m. A flying start allows the subject a 10m run-up before crossing the start line and timing commencement. Players started in a standing position with their preferred foot 0.5m behind the starting line. Modified 505 COD Test: Like the traditional 505 COD test but it involves a stationary start. Hexagon Test: A standard hexagon test was applied. On Court COD Test: Players performed an adapted version of a previously published footwork test (41) and it was executed on one half of a regular badminton court.	Traditional 505 U19 (sec) = 2.46±0.1 Modified 505 U19 (sec) = 2.72±0.1 Hexagon U19 (sec) = 9.92±0.6 On-Court COD U19 (sec) = 11.07±0.7	The On-Court COD test is a useful and reliable mean to assess COD performance in youth badminton players and it is associated with acceleration, sprint and jump performance.

Annex 2. Balance Table.

Balance						
Article/ Reference	**Goal of the Study**	**Sample**	**Intervention**	**Methods / Balance Measuring Protocol**	**Results of Interest/ Cutoff Values**	**Main Conclusions**
(54)	To investigate the effects of PB training on dynamic balance and quickness performance of elite badminton athletes.	n = 16 elite male badminton athletes PB = 8 PT = 8	Two groups of athletes took part in a PB training or only PT training for 6 weeks. The dynamic stability and quick movement ability were assessed at baseline and after the intervention.	Participants stood on an in-ground force plate (Kistler 9281CA, KISTLER) and then jumped front or lateral with their dominant leg standing for 10 s.	Results with difference between PB group and PT group: PB Post Front DPSI = 0.381±0.003 PB Front COPap(cm): 72.20±10.81 PB Front COPml(cm): 60.55±6.23 PB Front COPpl(cm): 109.70±18.56 PB Lateral COPap(cm): 63.37±9.83	PB training can strengthen dynamic balance ability and improve the quickness performance of male elite badminton players.
(52)	To investigate the effect of PB training on the COD performance of badminton athletes.	n = 16 PB = 8 PT = 8	Two groups of athletes took part in a PB training or only PT training for 6 weeks. All participants were tested to assess the COD ability before and after the training period.	While barefoot, participants balanced themselves with one foot on the centre board of a commercially available YBT instrument (Move2Perform,). To perform the test, they need to place their hands on their hips and reach as far as possible by pushing the board with the reaching limb into the anterior, posteromedial, and posterolateral directions and return to the original start position.	Results with difference between pre and post-test: PB Post Dominant Foot = 104.94±7.21 PB Post Non-Dominant Foot = 104.78±7.35	PB training induced an overall better adaptation for the SEMO TEST, the 5-0-5 COD test, the YBT, and the RSI test than PT training. Considering that balance training is relatively time-efficient (20 min in the current study), it is suggested that adding such exercises would allow optimal training adaptations for badminton players.

Annex 2. Balance Table (Continuation).

Balance						
Article/ Reference	**Goal of the Study**	**Sample**	**Intervention**	**Methods / Balance Measuring Protocol**	**Results of Interest/ Cutoff Values**	**Main Conclusions**
(82)	To investigate the effect of a six-week PT program on dynamic balance and knee proprioception in female badminton players.	n= 22 healthy beginner female badminton players Experimental Group (ExG) = 12 CG = 10	The participants were randomly assigned to either CG or ExG. The ExG went through PT for six weeks. Pre- and postintervention YBT and photography test were used to assess dynamic balance and knee proprioception, respectively.	Participants were randomly divided into experimental and CG's. The ExG received PT training 20 min per session, three sessions per week for six weeks, whereas the CG continued with their own routine exercises. When the six-week training period was completed, the tests were recorded one-day after the last session of training.	Dynamic Balance (score): Post ExG = 99.12±7.60 Post CG = 88.20±7.59 Knee Proprioception 45° (CAD): Post ExG = 1.54±1.03 Post CG = 3.90±1.92 Knee Proprioception 60° (CAD): Post ExG = 2.00±1.10 Post CG = 3.45±1.30	The results of this study demonstrated that a six-week PT training program improved dynamic balance and knee proprioception in beginner female badminton players. Hence, PT training can be utilized by badminton coaches and players to improve dynamic balance and knee proprioception, which in turn may reduce non-contact Anterior Cruciate Ligament (ACL) injuries.
(60)	To Investigate the effects of INT on injury prevention and the performance of professional female badminton athletes.	n = 38 elite male badminton athletes HG = 22 LG = 16	Two groups of athletes took part in an 8-week INT program consisting of four 90-min sessions each week. The asymmetries in movement, physical fitness, and special abilities were tested before and after the intervention.	The dynamic balance test uses the single-leg side hop test, and athletes should remain standing on one foot and jump to the opposite side with full on the ground with the other foot. When landing on one foot, they keep their body above 3 s to record effective results.	Results with very significant difference between groups: HG Post Left = 126:78±5:38 HG Post Right = 129:11±2:87	INT can effectively improve the asymmetry of female badminton athletes' limbs, prevent sports injury, and improve the athlete's performance ability. Athletes in different risk groups have certain differences in the degree of improvement in their motor skills.

Annex 2. Balance Table (Continuation).

Balance						
Article/ Reference	**Goal of the Study**	**Sample**	**Intervention**	**Methods / Balance Measuring Protocol**	**Results of Interest/ Cutoff Values**	**Main Conclusions**
(62)	To investigate the effect of combined balance and PT training on knee function and proprioception of elite badminton athletes.	n = 16 elite male badminton players PB = 8 PT = 8	The participants were randomly assigned to a PB and PT group. The PB group performed balance combined with PT training three times a week over 6 weeks (40 min of PT and 20 min of balance training); while the PT group undertook only PT training for the same period (3–4 sets × 8–12 reps for each exercise). Both groups had the same technical training of badminton.	The single hop for distance, triple hop for distance, cross-over hop for distance and timed for 6 m hop were measured, respectively. Smart Speed device (Fusion Sport, Coopers) was set for Time for six m hop to record the time. After hopping, participants needed to stand with a single leg for 2 s to make results effective.	PB Post Intervention: DAP (cm): 71.50±10.31 NDAP (cm): 72.20±10.81 DML (cm): 80.44±10.60 NDML (cm): 80.76±7.22 PT Post Intervention: DAP (cm): 79.58±8.11 NDAP (cm): 83.72±8.05 DML (cm): 82.11±11.60 NDML (cm): 87.81±15.60	In elite badminton players, intervention using PB holds great promise to augment the benefits for knee function compared to the intervention using PT only, and at the same time, with at least comparable benefits for proprioception.

Annex 3. Body Composition Table.

Body Composition						
Article/ Reference	**Goal of the Study**	**Sample**	**Intervention**	**Methods / BC Measuring Protocol**	**Results of Interest/ Cutoff Values**	**Main Conclusions**
(64)	To determine whether carbohydrate ingestion affects badminton performance.	n = 9 male badminton players	All participants performed a Vo2 Max test on a treadmill (Woodway GmbH) before data collection. This allowed for the identification of participants' Vo2max and Maximum Heart Rate (MHR) to determine relative intensity during the experimental trials. The participants then completed two experimental trials separated by one week, in which they consumed 1L of a 6.4% carbohydrate-electrolyte drink or a similar tasting placebo drink with identical electrolyte composition.	BM and height (stadiometer) were measured.	Height (m): 1.77±0.52 BM (kg): 80.6±7.9	The results suggest that only the long serve is influenced by fatigue and carbohydrate tended to prevent the deterioration in performance.

Annex 3. Body Composition Table (Continuation).

Article/ Reference	Goal of the Study	Sample	Intervention	Methods / BC Measuring Protocol	Results of Interest/ Cutoff Values	Main Conclusions
(69)	To analyse peripheral Brain-Derived Neurotrophic Factor (BDNF) levels and psychophysiological parameters in youth badminton athletes during the season and to determine the relationship between variables.	n = 14 young badminton athletes (age = 16.8 ± 1.8 y) Female = 9 Male = 5	All participants were assessed over the season (preseason, middle season, and final season). Serum Brain-Derived Neurotrophic Factor (sBDNF) was determined during the preseason and final season. Sleep time, total physical activity, and time in vigorous activity were measured using an accelerometer. The FFM, SMM, FM, handgrip strength, cardiorespiratory fitness (VO2max), and dietary intake were evaluated during the season. Cognitive tasks and mood, were also evaluated.	BM was measured using an electronic scale (Filizola PL 50; Filizola Ltda, São Paulo, Brazil) with an accuracy of 0.1 kg and a maximum capacity of 150 kg, and stature was measured using a fixed stadiometer (Sanny, São Paulo, Brazil), with an accuracy of 0.1 cm. A spectral BI analysis and accompanying software (InBody S10; InBody, Gangnam-gu, Seoul, Korea) was used to measure FM, FFM, and SMM.	Height Male (cm): 171.2±4.6 Height Female (cm): 164.0±4.7 Results with significant difference from preseason: Male: Bodyweight Final (kg): 64.8±4.3 FM Final (%):14.2±3.5 FFM Final (%):55.6±4.7 SMM Final (kg): 31.4±2.8	Youth badminton athletes decreased their sBDNF levels, sleep time, carbohydrate, and calorie intake across the season. The athletes improved in cognitive function; however, only the females improved in body composition, and the males improved their VO2max in the middle season. The sBDNF levels were positively correlated with the VO2max in the preseason, and no correlations were observed among the sBDNF and psychological parameters, sleep time, and sport performance during the season.

Annex 3. Body Composition Table (Continuation).

Body Composition						
Article/ Reference	**Goal of the Study**	**Sample**	**Intervention**	**Methods / BC Measuring Protocol**	**Results of Interest/ Cutoff Values**	**Main Conclusions**
(59)	To assess somatic build and physical fitness of elite and sub-elite Polish badminton players and to identify key traits that determine achieving sporting success in badminton.	n = 20 men from the Polish National Badminton Teams A and B Elite (A) = 9 Sub-Elite (B) = 11	In all participants body height, arm span, BM, BF, FFM and BMI were assessed. Fitness tests included two badminton-specific on-court movement tests and cycloergometer test to assess Vo2 Max.	Body height was measured using a stadiometer (holtain limited, crymych, uK) with the participant standing barefoot with the upper back buttock and heels pressed against the upright position of the instrument. Arm span was measured with measuring tape from the tip of the middle finger on one hand to the tip of the middle finger on the other hand. BM was measured using a Tanita Bc-418 Ma (Tokyo, Japan) segmental body composition analyser with accuracy to 0.1 kg. after checking the scale was reading zero, the participant wearing light clothes stood on the centre of the scale without support and with the weight distributed evenly on both feet, the head was up, and eyes looked directly ahead. The BF percentage and FFM was estimated by BI method using Tanita Bc-418 Ma device.	Height (cm) A: 185.0±5.1 B: 183.3±4.3 Arm span (cm): A: 186.0±5.2 B: 184.7±4.37 BM (kg): A: 82.7±4.6 B: 72.8±3.7 BMI (kg/m2): A: 24.2±1.8 B: 21.7±1.3 BF (%): A: 13.0±4.0 B: 9.2±1.9 FFM (kg): A: 71.8±3.3 B: 66.0±3.1	Relatively small body size of badminton players can be considered advantageous in sport competitions. Aerobic capacity contributes to achieving sport success in badminton to a much lower degree than the badminton-specific on-court skills.

Annex 3. Body Composition Table (Continuation).

Body Composition						
Article/ Reference	**Goal of the Study**	**Sample**	**Intervention**	**Methods / BC Measuring Protocol**	**Results of Interest/ Cutoff Values**	**Main Conclusions**
(58)	To assess general and specific lower and upper limb force, shuttlecock velocity, displacement ability, and the anthropometric characteristics of badminton players at 5 skill levels, and to predict individual players' number of points.	n = 83 badminton players Novice = 15 Intermediate = 16 Skilled = 23 Highly Skilled = 14 Elite = 15	The subjects were first divided into one of five groups. The number of points scored for each player performing tournaments (excluding novices) during the entire season was used as a continuous and dependent variable after logarithmic transformation for correlational study. Anthropometric measurements of height, mass, percentage of fat, and muscle were recorded, along with shuttlecock maximal velocity during smashes. Upper limb power and lower limb force were recorded during jumps and handgrip strength. We also assessed players' ability to move quickly around the court through an on-court MRSAB test with 4 changes of direction. All variables were combined in a multiple regression model.	Measurements were taken using the standardized techniques recommended by the International Society for the Advancement of Kinanthropometry (26). Body height was measured using an anthropometer with 0.1-cm accuracy. For measuring height, each subject stood erect, with bare feet and with their head on the Frankfort plane. We also used a stadiometer (Matsport, SaintIsmier, France) to measure the perpendicular distance from the floor to the vertex (the crown of the head). BM, percentage of BF, and percentage of muscle mass were measured using BI scales (Weinberger model DJ-156; Weinberger GmbH & Co., Haan, Germany). Finally, we calculated the BMI (in kg/m2) as the ratio of the mass (kg) to the squared height (m).	Height (cm): Elite: 182±6.2 BM (kg): Elite: 74.4±6 BMI (kg/m2): Elite: 22.5±2.5 BF (%): Elite: 15.4±4.2 Muscle Mass (%): Elite: 43.8±2.3	The main findings were that the major contributor to skill level is shuttlecock velocity (r =0.86), the time taken to move during the MRSAB test (r = 0.85) and the Squat Jump (SJ) height (r = 0.53). Anthropometric factors contribute only a little to the individual score point (2%).
(68)	To compare the effects of Ballistic Six training and TheraBand exercises on shoulder strength, agility, speed, and function in novice badminton players.	n = 40 subjects of both genders who play badminton for more than a year.	The participants were randomized into two groups, Group A (Ballistic Six Exercise group) and Group B (TheraBand exercise group). Assessments done were the SMBT for shoulder strength, Closed Kinetic Chain Upper Extremity Stability Test (CKUCEST) for agility, Plate Tapping Test (PTT) for speed and KJOC for shoulder function. Assessments were done at baseline, post 8 weeks of training and at the end of 6 months.	BMI was Measured.	BMI (kg/m^2): Ballistic Six Exercise Group: 21.95 TheraBand Exercise Group: 20.81	The study concluded that adding of Ballistic Six PT training for novice badminton players would increase the shoulder strength, agility, speed, and function than the TheraBand exercises.

Annex 3. Body Composition Table (Continuation).

Body Composition						
Article/ Reference	**Goal of the Study**	**Sample**	**Intervention**	**Methods / BC Measuring Protocol**	**Results of Interest/ Cutoff Values**	**Main Conclusions**
(49)	To assess the occurrence of muscle damage after a simulated badminton match and its influence on physical and haematological parameters.	n = 16 Competitive male badminton players	Before and just after a 45-min simulated badminton match, maximal isometric force and badminton specific running/movement velocity were measured to assess muscle fatigue. Blood samples were also obtained before and after the match.	FM was calculated from six skinfold measurements (triceps, subscapular, umbilicus, suprailium, thigh, and lower leg) according to the equations by Carter (1982). FFM was calculated by subtracting FM from total mass, and muscle mass (expressed as a percentage of total mass) was calculated by subtracting bone and residual mass from FFM.	Height (cm): 174.1±5.8 BM (kg): 71.8±7.9 BF (%): 8.3±1.2 Muscle Mass (%): 51.2±1.3	A simulated badminton match modified haematological parameters of whole blood and serum blood that indicate the occurrence of muscle fibre damage. However, the level of muscle damage did not produce decreased muscle performance.
(70)	To examine AHD and shoulder isometric strength for ER and IR in national elite badminton players.	n = 7 Elite badminton players with asymptomatic shoulders from the Danish national badminton team. Male = 5 Female = 2	Shoulder AHD, isometric strength in ER and IR were bilaterally assessed with ultrasonography and a Hand-Held Dynamometer (HHD).	Height, BM, BMI and forearm length were measured.	Height (cm): 1.84±0.07 BM (kg): 77±7 BMI (kg/m^2): 23±1 Forearm Length (m): 0.26±0.01	This preliminary study demonstrates that shoulder ER strength is strongly associated with AHD size, largely reflecting supraspinatus tendon-muscle hypertrophy because of sport-specific adaptation in national elite badminton players with asymptomatic shoulders. These novel data also suggest that habitual loading of the shoulder improves the supraspinatus tendon size, which may lower the mechanical stress and potentially reduce the risk of injury. These warrants strengthening the shoulder external rotators as a potential strategy to reduce the risk of future shoulder injury.

Annex 3. Body Composition Table (Continuation).

Body Composition						
Article/ Reference	**Goal of the Study**	**Sample**	**Intervention**	**Methods / BC Measuring Protocol**	**Results of Interest/ Cutoff Values**	**Main Conclusions**
(63)	To confirm the correlation between racket velocity during the forehand smash movements with shoulder extensor strength and internal rotator strength in the neutral and abducted positions.	n = 14 Collegiate badminton players. Male = 5 Female = 9	Measurements performed were shoulder strength, using torque calculated from the upper extremity length and the isometric force, and racket velocity during the forehand smash movements. The shoulder extensor strength and internal rotator strength were measured in the neutral and abducted positions.	Height, BM, forearm length and upper extremity length were measured.	Height (cm): 164.4±8.9 BM (kg): 58.1±6.7 Forearm Length (cm): 31.4±2.5 Upper Extremity Length (cm): 59.7 ±4.8	The shoulder internal rotator strength in the abducted external rotated position are suitable measurements for evaluating badminton players.
(23)	To investigate whether the test items used in the Flemish Sports Compass (FSC) are able to differentiate participants from Flemish Top Sport Academies in nine sports, i.e. badminton, basketball, gymnastics, handball, judo, soccer, table tennis, triathlon and volleyball.	n = 141 elite young male athletes (16.1 ± 0.8 years). Badminton =12	The participants completed the 22 generic tests of the FSC, consisting of anthropometrical, physical performance and motor coordination measurements, assessed by 11 experienced examiners.	Height (0.1 cm, Harpenden, Portable Stadiometer, Holtain, UK), sitting height (0.1 cm, Harpenden, Sitting Table, Holtain, UK) and BM and BF percentage (0.1 kg, Tanita, BC-420SMA) were assessed according to previously described procedures (Lohman, Roche, & Martorell, 1988) and manufacturer guidelines.	Height (cm): 175.2±7.1 Sitting Height (cm): 92.6±3.7 BM (kg): 63.4±7.6 BF (%): 10.9±3.9 BMI (kg/m^2): 20.6±2.1	The FSC confirms that elite adolescent boys show differences in generic talent characteristic that distinguish them according to their sport. The FSC can also identify relevant talent characteristics for each sport, which could be used in the purposeful orientation of talented individuals according to their strengths and their weaknesses.
(66)	To investigate the relationships between shuttlecock velocity during a badminton forehand smash with and without jump, strength of upper limb muscles, VJH and to analyse differences in these parameters for each gender.	n = 14 Polish National Badminton Team members Male = 7 Female = 7	This study examined members of the Polish National Badminton Team seven women and seven men. A special torque meter was used to assess the strength of the upper limb muscles. VJ's were performed on a force plate. Shuttlecock velocity was measured using Vicon motion capture system.	Height and BM were assessed.	Female: Height (cm): 163.89±7.44 BM (kg): 59.84±6.68 Male: Height (cm): 184.76±7.11 BM (kg): 77.27 ± 4.72	The jump before smash is not used to hit the shuttle from the highest point, but to gain time to correctly prepare the phase of stroke while being in the air.

Annex 3. Body Composition Table (Continuation).

Body Composition						
Article/ Reference	**Goal of the Study**	**Sample**	**Intervention**	**Methods / BC Measuring Protocol**	**Results of Interest/ Cutoff Values**	**Main Conclusions**
(67)	To develop a Badminton-Specific Speed Test (BST), which includes a random movement pattern comparable with real game situations and evaluate the reproducibility and specificity of the developed test. It was the intention that the BST should be able to differentiate between elite, less skilled, and non-badminton players and with test reproducibility comparable with simple sprint tests.	n = 61 Healthy male subjects Elite = 20 Skilled = 21 Non-Badminton Players = 20	Day-to-day variation in elite players was assessed, and specificity of the test was evaluated by comparing 30-m sprint performance and time to complete the BST in 20 elite players, 21 skilled players, and 20 age-matched physical active subjects (non-badminton players).	Height and BM were assessed.	Elite: Height (cm): 186.7±7.0 BM (kg): 77.7±6 Skilled: Height (cm): 182.2±5.1 BM (kg): 77.8±9.5	The BST may be valuable for evaluation of short-term maximal movement speed in badminton players. Thus, the BST seems to be sport specific, as it may discriminate between groups (elite, less trained players, and non-badminton players) with similar sprinting performance, and the low test-retest variation may allow for using the BST to evaluate longitudinal changes, for example, training effects or seasonal variations.
(57)	To develop a new sport-specific, repeated-sprint ability test involving 4 changes of direction, namely, the MRSAB test for badminton players, and to determine its validity by comparing the results of 5 different skill levels. It was also to assess the link between the new test and neuromuscular lower limb and physiological variables.	n = 42 badminton players ranging from novice to elite levels. Elite = 9 Highly Skilled = 9 Skilled = 9 Intermediate = 9 Novice = 6	The participants were separated into 5 groups to perform the MRSAB test at the same time of day, on 2 occasions, separated by at least 48 hours. The best time, mean time, and fatigue index were measured. Heart rate and blood lactate concentration were also recorded to determine the participants' physiological responses to the test.	In the first session, physiological, anthropometric, and neuromuscular lower limb variables were first measured for each badminton player. A shuttle-run test was used to estimate VO^2max, heart rate, lactate, height, mass, BMI, BF, and muscle mass.	Elite: Height (cm): 182.0±6.7 BM (kg): 76.0±6.6 BMI (kg/m^2): 23.1±2.9 BF (%): 16.4±4.1 Muscle Mass (%): 43.5±2.5	The results show that the MRSAB test is valid, because it differentiates between the 5 skill levels for best time, mean time and fatigue index and offers a reliable method for testing badminton players, with no differences between the sessions. Moreover, the link between mean time and neuromuscular variables, such as jump height in squats and countermovements and with VO^2max reveals that this test uses a combination of the anaerobic and aerobic systems, thus, it can be used by trainers either to improve movement ability or increase these physical qualities.

Annex 3. Body Composition Table (Continuation).

Body Composition						
Article/ Reference	**Goal of the Study**	**Sample**	**Intervention**	**Methods / BC Measuring Protocol**	**Results of Interest/ Cutoff Values**	**Main Conclusions**
(65)	To compare bilateral absolute and relative shoulder extension-flexion peak moments of volleyball, handball, underwater hockey, and badminton players and to determine whether the decline in the average moment, power, and work measures were consistent with observed bilateral peak moment relationships.	n = 44 healthy male athletes Badminton = 11	All participants were first evaluated in regard to anthropometric parameters. After the anthropometric evaluation, participants then proceeded to be tested using a dynamometer to compare bilateral absolute and relative shoulder extension-flexion peak moments.	The anthropometric parameters (BF, BM, and lean BM) were assessed using BI analysis (Tanita 418-MA Japan). Height 148 was also measured by means of a stadiometer in the 149-standing position (Holtain Ltd., UK).	Height (cm): 173.90±6.33 BM (kg): 68.49±7.61 Lean BM (kg): 61.28±4.78 BF (%): 10.21±4.22	Peak moment only measurements could be inadequate to determine strength discrepancies among different sports branches and the assessment of the declines in the average moment, work and power parameters between the sets may be more beneficial for the examination of shoulder strength characteristics in athletes.
(60)	To Investigate the effects of INT on injury prevention and the performance of professional female badminton athletes.	n = 38 elite male badminton athletes High-Risk Group (HG) = 22 LG = 16	Two groups of athletes took part in an 8-week INT program consisting of four 90-min sessions each week. The asymmetries in movement, physical fitness, and special abilities were tested before and after the intervention.	Height, BMI, and BM (kg) were assessed.	HG: Height (m): 1.70±0.03 BM (kg): 58:0±2.4 BMI (kg/m^2): 19.23±0.5 LG: Height (m): 1.72±0.04 BM (kg): 59.0±3.1 BMI (kg/m^2): 19.66 ± 0.7	INT can effectively improve the asymmetry of female badminton athletes' limbs, prevent sports injury, and improve the athlete's performance ability. Athletes in different risk groups have certain differences in the degree of improvement in their motor skills.
(54)	To investigate the effects of combined PB training on dynamic balance and quickness performance of elite badminton athletes.	n = 16 elite male badminton athletes PB= 8 PT = 8	Two groups of athletes took part in a balance combined with PT training or only PT training for 6 weeks. The dynamic stability and quick movement ability were assessed at baseline and after the intervention.	Height and BM (kg) were assessed.	PB: Height (cm): 177.75±5.06 BM (kg): 68.13±7.22 PT: Height (cm): 179.13±6.06 BM (kg): 69.88±8.94	PB training can strengthen dynamic balance ability and improve the quickness performance of male elite badminton players.

Annex 3. Body Composition Table (Continuation).

Body Composition						
Article/ Reference	Goal of the Study	Sample	Intervention	Methods / BC Measuring Protocol	Results of Interest/ Cutoff Values	Main Conclusions
(52)	To investigate the effect of PB training on the COD performance of badminton athletes.	n = 16 BP = 8 PT = 8	Two groups of athletes took part in a balance combined with PT training or only PT training for 6 weeks. All participants were tested to assess the COD ability before and after the training period.	Height and BM (kg) were assessed.	BP: Height (cm): 177.8±5.1 BM (kg): 68.1±7.2 PL: Height (cm): 179.1±6.1 BM (kg): 69.88±8.94	PB training induced an overall better adaptation for the SEMO TEST, the 5-0-5 COD test, the YBT, and the RSI test than PT. Considering that balance training is relatively time-efficient (20 min in the current study), it is suggested that adding such exercises would allow optimal training adaptations for badminton players.
(61)	To investigate the effect of a six-week PT training program on dynamic balance and knee proprioception in female badminton players.	n= 22 healthy beginner female badminton players ExG = 12 CG= 10	The participants were randomly assigned to either CG or ExG. The ExG went through PT training PT for six weeks. Pre- and postintervention YBT and photography test were used to assess dynamic balance and knee proprioception, respectively.	BMI was assessed.	BMI (kg/m^2): ExG: 22.95±3.07 CG: 22.60±1.98	The results of this study demonstrated that a six-week PT training program improved dynamic balance and knee proprioception in beginner female badminton players. Hence, PT training can be utilized by badminton coaches and players to improve dynamic balance and knee proprioception, which in turn may reduce non-contact ACL injuries.

Annex 3. Body Composition Table (Continuation).

Body Composition						
Article/ Reference	**Goal of the Study**	**Sample**	**Intervention**	**Methods / BC Measuring Protocol**	**Results of Interest/ Cutoff Values**	**Main Conclusions**
(55)	This study investigated the short-term effects of LFCM consumption on DOMS and performance in female badminton players.	n = 7 female badminton players LFCM = 4 Placebo Group = 3 After one week the individuals switched groups.	The participants were randomly assigned to 1 week of LFCM (500 mL) or placebo (water, 500 mL) consumption in a crossover design. They consumed LFCM or water immediately after each training session during 1-week. Performance variables were assessed pre- and post-intervention. In addition, the Visual Analogue Scale was used to assess DOMS before, immediately after, and 24 and 48 h after each training session.	Height and BM of all participants were measured using a stadiometer (Seca, Hamburg, Germany) and a scale (Beurer, Germany; model: PS06) with a reported accuracy of 0.1 cm and 0.01 g, respectively. BMI was calculated using the Ancel Keys equation by dividing BM (kg) by height squared (m2).	Height (cm): 163.8±4.1 BM (kg): 58.7±0.9 BMI (kg/m²): 21.9±3.5	There were no significant changes in maximum anaerobic power, agility, and maximum handgrip strength. LFCM, as a post-exercise beverage, may help speed recovery in female badminton players leading to increased aerobic, anaerobic and strength performance indices, increased Time to Exhaustion (TTE), and decreased muscle soreness and Rate of Perceived Exertion (RPE).
(81)	To compare the effects of four weeks of PT training and EMS of knee extensor and ankle plantar flexor muscles on agility, 30-m sprint, lower limb explosive power and jumping ability amongst badminton players.	n = 90 state level badminton players PT = 30 EMS = 30 CG = 30	Pretest-Post-test Design with two ExG's and a CG was used. The PT training was carried out two times/week while the EMS training was four times/week for four weeks The CG did not receive any intervention. All three groups continued their general badminton training throughout the study. Players were assessed for agility, a 30-m sprint, a SBJ and a VJH before and after four weeks.	Height, BMI, and BM were assessed.	PT: Height (m): 1.68±0.03 BM (kg): 61.46±5.97 BMI (kg/m²): 21.59±1.85 EMS: Height (cm): 1.72±0.03 BM (kg): 60.4±1.91 BMI (kg/m²): 20.25±1.17 CG: Height (cm): 1.62±0.03 BM (kg): 56.4±6.2 BMI (kg/m²): 21.26±1.99	PT training showed significant improvement in sprint time and jumping ability, whereas EMS training showed significant Improvement only in jumping ability.

Annex 3. Body Composition Table (Continuation).

Body Composition						
Article/ Reference	**Goal of the Study**	**Sample**	**Intervention**	**Methods / BC Measuring Protocol**	**Results of Interest/ Cutoff Values**	**Main Conclusions**
(51)	To assess the reliability of a specific COD test (i.e., "OnCourt COD test") in youth badminton players, evaluate the effect of age on On-Court COD performance, and examine its correlations with linear speed, COD speed, and VJ tests.	n = 42 young badminton players (27 males and 15 females) Under 17 = 21 Under 19 = 21	42 young badminton players were divided into two age groups and took part in assessment routines which took part in two different days. All tests were performed in the same order, using the same testing devices, measurement protocols, and experienced evaluators.	Height and BM were assessed.	Height (cm): 175±4.7 BM (kg): 64.2±7.4	The On-Court COD test is a useful and reliable means to assess COD performance in youth badminton players and it is associated with acceleration, sprint and jump performance.

Annex 4. Annex 4 – Cardiovascular Endurance Table.

Cardiovascular Endurance						
Article/ Reference	**Goal of the Study**	**Sample**	**Intervention**	**Methods / CE Measuring Protocol**	**Results of Interest/ Cutoff Values**	**Main Conclusions**
(55)	This study investigated the short-term effects of LFCM consumption on DOMS and performance in female badminton players.	n = 7 female badminton players LFCM = 4 Placebo Group = 3 After one week, the individuals switched groups.	The participants were randomly assigned to 1 week of LFCM (500 mL) or placebo (water, 500 mL) consumption in a crossover design. They consumed LFCM or water immediately after each training session during 1-week. Performance variables were assessed pre- and post-intervention. In addition, the Visual Analogue Scale was used to assess DOMS before, immediately after, and 24 and 48 h after each training session.	A standard YoYo intermittent test was used to assess aerobic power and TTE. intermittent test. All performance tests were completed before beginning the protocol (baseline) and at the end of the 1-week intervention.	Aerobic Power (ml/kg/min): Baseline: 38.6±0.32 Post Test Placebo: 38.9±0.32 Post Test LFCM: 39.1±0.56 TTE (sec): Baseline: 262.8±39 Post Test Placebo: 301.4±38.4 Post Test LFCM: 325.7±67	There were no significant changes in maximum anaerobic power, agility, and maximum handgrip strength. LFCM, as a post-exercise beverage, may help speed recovery in female badminton players leading to increased aerobic, anaerobic and strength performance indices, increased TTE, and decreased muscle soreness and RPE.

Annex 4. Cardiovascular Endurance Table (Continuation).

Cardiovascular Endurance						
Article/ Reference	**Goal of the Study**	**Sample**	**Intervention**	**Methods / CE Measuring Protocol**	**Results of Interest/ Cutoff Values**	**Main Conclusions**
(64)	To determine whether carbohydrate ingestion affects badminton performance.	n = 9 male badminton players	All participants performed a Vo^2max test on a treadmill (Woodway GmbH) before data collection. This allowed for the identification of participants' Vo^2max and MHR in order to determine relative intensity during the experimental trials. The participants then completed two experimental trials separated by one week, in which they consumed 1 L of a 6.4% carbohydrate-electrolyte drink or a similar tasting placebo drink with identical electrolyte composition.	The Vo^2max test was performed on a treadmill at an initial 1% gradient and at a comfortable speed for the athlete. Speed was increased every 2 min for the first 6 min, after which the gradient was increased by 2% each min until volitional exhaustion. Heart rate (Garmin Forerunner) was monitored throughout the test.	Vo^2Max (ml/kg/min): 52.1±10.9 MHR (bpm): 200±11	The results suggest that only the long serve is influenced by fatigue and carbohydrate tended to prevent the deterioration in performance.
(69)	To analyse peripheral BDNF levels and psychophysiological parameters in youth badminton athletes during the season and to determine the relationship between variables.	n = 14 young badminton athletes (age = 16.8±1.8 years) Female = 9 Male = 5	All participants were assessed over the season (preseason, middle season, and final season). sBDNF was determined during the preseason and final season. Sleep time, total physical activity, and time in vigorous activity were measured using an accelerometer. The FFM, SMM, FM, handgrip strength, cardiorespiratory fitness (VO^2max), and dietary intake were evaluated during the season. Cognitive tasks and mood, were also evaluated.	The Yo-Yo endurance test 2 was used. The VO^2max (in millilitre per kilogram per min) was calculated using the equation 24.4 + 6 × (final velocity [in kilometre per hour]) for athletes aged ≥ 18 years or 31.025+ (3.238 × final velocity) − (3.248 ×age) + 0.1536 × (final velocity × age) for athletes aged <18 years.	Female Athletes (ml/kg/min): Preseason: 38.5±0.8 Middle Season: 39.3±0.6 Final Season: 38.8±0.3 Male Athletes (ml/kg/min): Preseason: 40.4±1.0 Middle Season: 42.6±1.2 Final Season: 40.7±2.0	Youth badminton athletes decreased their sBDNF levels, sleep time, carbohydrate, and calorie intake across the season. The athletes improved in cognitive function; however, only the females improved in body composition, and the males improved their VO^2max in the middle season. The sBDNF levels were positively correlated with the VO^2max in the preseason, and no correlations were observed among the sBDNF and psychological parameters, sleep time, and sport performance during the season.

Annex 4. Cardiovascular Endurance Table (Continuation).

Cardiovascular Endurance						
Article/ Reference	**Goal of the Study**	**Sample**	**Intervention**	**Methods / CE Measuring Protocol**	**Results of Interest/ Cutoff Values**	**Main Conclusions**
(59)	To assess somatic build and physical fitness of elite and sub-elite Polish badminton players and to identify key traits that determine achieving sporting success in badminton.	n = 20 men from the Polish National Badminton Teams A and B Elite (A) = 9 Sub-Elite (B) = 11	In all participants body height, arm span, BM, BF, FFM and BMI were assessed. Fitness tests included two badminton-specific on-court movement tests and cycloergometer test to assess Vo2 Max.	Aerobic capacity was measured by an exercise physiologist, using an incremental aerobic capacity test conducted on a cycloergometer according to Bruce's procedure.30 The test began with a 5-min-long warm-up session at a minimal load (7.5% of BM). participants were asked to maintain a constant speed at 50 revolutions per min. The load increased every 3 min by 25 watts until oxygen consumption ceased to increase. Vo^2Max was assessed using the Start2000M (MeS, Poland) software for ergospirometric measurements.	Elite A (ml/kg/min): 55.9±7.1 Sub-Elite B (ml/kg/min): 57.2±3.5	Relatively small body size of badminton players can be considered advantageous in sport competitions. Aerobic capacity contributes to achieving sport success in badminton to a much lower degree than the badminton-specific on-court skills.
(23)	To investigate whether the test items used in the FSC are able to differentiate participants from Flemish Top Sport Academies in nine sports, i.e. badminton, basketball, gymnastics, handball, judo, soccer, table tennis, triathlon, and volleyball.	n = 141 elite young male athletes (16.1±0.8 years). Badminton = 12	The participants completed the 22 generic tests of the FSC, consisting of anthropometrical, physical performance and motor coordination measurements, assessed by 11 experienced examiners.	An Endurance SR test was used to assess cardiovascular endurance. The SR and sprint test were recorded with MicroGate Racetime2 chronometry and Polifemo Light photocells at an accuracy of 0.001 s (MicroGate, Italy)	Badminton (min): 17.634±0.604	The FSC confirms that elite adolescent boys show differences in generic talent characteristic that distinguish them according to their sport. The FSC can also identify relevant talent characteristics for each sport, which could be used in the purposeful orientation of talented individuals according to their strengths and their weaknesses.

Annex 4. Cardiovascular Endurance Table (Continuation).

Cardiovascular Endurance						
Article/ Reference	**Goal of the Study**	**Sample**	**Intervention**	**Methods / CE Measuring Protocol**	**Results of Interest/ Cutoff Values**	**Main Conclusions**
(41)	To investigate the physiological response of elite badminton players in a sport-specific fitness test.	n = 12 Hong Kong national badminton team players	All participants performed a field test on a badminton court. Six light bulbs were connected to a programming device causing individual bulbs to light up in a given sequence. The players were instructed to react to the flashes by running towards them, and striking shuttles mounted in the vicinity of the bulbs. Exercise intensity was controlled by altering the interval between successive lightings.	The field test was executed in one half of a badminton court. Six light bulbs were individually mounted on posts, with one shuttle at the top end of each post. The lights were connected to a programming device located outside the court. The subjects were instructed to run from a central point towards each shuttle as soon as the corresponding bulb was lit and to strike the shuttle in a technically appropriate manner. For the forecourt and midcourt light flashes, subjects performed a front and side lunge. For the rear court flashes, it was necessary to imitate a backward jump smash and land between the court lines, and then return to the central point. The test consisted of successive 3 min periods of exercise.	MHR (bpm): 187±8 Heart Rate 5 min after load end (bpm): 115±11	This field test allows the calculation of reasonable estimates of badminton athletes' fitness levels and may also be included as one of the means of on-court fitness conditioning. The regular, repeated physiological monitoring with on-field stimulation of badminton stroke moves is welcomed by the Hong Kong national coaches and may give a good indication of improvement or otherwise in training of each individual athlete.
(57)	To develop a new sport-specific, repeated-sprint ability test involving 4 changes of direction, namely, MRSAB test for badminton players, and to determine its validity by comparing the results of 5 different skill levels. It was also to assess the link between the new test and neuromuscular lower limb and physiological variables.	n = 42 novice to elite level badminton players Elite = 9 Highly Skilled = 9 Skilled = 9 Intermediate = 9 Novice = 6	The participants were separated into 5 groups to perform the MRSAB test at the same time of day, on 2 occasions, separated by at least 48 hours. The best time, mean time, and fatigue index were measured. Heart rate and blood lactate concentration were also recorded to determine the participants' physiological responses to the test.	A standard SR test was used to estimate VO^2max. The equation used to estimate Vo^2Max was as follows: $Vo^2max = 31.025 + 3.238 \times$ maximum SR speed 23.248 x age + 0.1536 x age x maximum SR speed	Vo^2Max (ml/kg/min): Elite: 61.2±2.1 Highly Skilled: 57.4±3.1 Skilled: 54.1±2.9 Intermediate: 49.6±2.1 Novice: 48.1±3.3	The results show that the MRSAB test is valid, because it differentiates between the 5 skill levels for best time, mean time and fatigue index and offers a reliable method for testing badminton players, with no differences between the sessions. Moreover, the link between mean time and neuromuscular variables, such as jump height in squats and countermovements and with _ VO^2max reveals that this test uses a combination of the anaerobic and aerobic systems, thus, it can be used by trainers either to improve movement ability or increase these physical qualities.

Annex 5. Coordination Table.

Coordination						
Article/Reference	**Goal of the Study**	**Sample**	**Intervention**	**Methods / Coordination Measuring Protocol**	**Results of Interest/ Cutoff Values**	**Main Conclusions**
(23)	To investigate whether the test items used in the FSC can differentiate participants from Flemish Top Sport Academies in nine sports, i.e., badminton, basketball, gymnastics, handball, judo, soccer, table tennis, triathlon, and volleyball.	n = 141 elite young male athletes (16.1±0.8 years). Badminton = 12	The participants completed the 22 generic tests of the FSC, consisting of anthropometrical, physical performance and motor coordination measurements, assessed by 11 experienced examiners.	Gross motor coordination was evaluated by means of three subtests of the KTK; (1) backward balance: walking backwards along balance beams of decreasing width (6 cm; 4.5 cm and 3 cm, respectively); (2) jumping sideways: two-legged jumping sideways over a wooden slat (2 × 15 s), summing the number of jumps over the two trials; (3) moving sideways: moving sideways on wooden platforms (2 × 20 s), summing the number of relocations over two trials.	Dynamic Balance (n): 62±9 Jumping Sideways (n): 105±9 Moving Sideways (n): 71±6	The FSC confirms that elite adolescent boys show differences in generic talent characteristic that distinguish them according to their sport. The FSC can also identify relevant talent characteristics for each sport, which could be used in the purposeful orientation of talented individuals according to their strengths and their weaknesses.

Annex 6. Flexibility Table.

Flexibility						
Article/Reference	**Goal of the Study**	**Sample**	**Intervention**	**Methods / Flexibility Measuring Protocol**	**Results of Interest/ Cutoff Values**	**Main Conclusions**
(23)	To investigate whether the test items used in the (FSC) can differentiate participants from Flemish Top Sport Academies in nine sports, i.e., badminton, basketball, gymnastics, handball, judo, soccer, table tennis, triathlon, and volleyball.	n = 141 elite young male athletes (16.1±0.8 years). Badminton = 12	The participants completed the 22 generic tests of the FSC, consisting of anthropometrical, physical performance and motor coordination measurements, assessed by 11 experienced examiners.	Hamstring and lower back flexibility were assessed by the sit-and-reach test of the European Test of Physical fitness (83). The shoulder rotation test was used to evaluate shoulder flexibility (84) with an accuracy of 0.5 cm.	Sit and Reach (cm): 29.0±4.7 Shoulder Rotation (cm): 92.0±14.5	The FSC confirms that elite adolescent boys show differences in generic talent characteristic that distinguish them according to their sport. The FSC can also identify relevant talent characteristics for each sport, which could be used in the purposeful orientation of talented individuals according to their strengths and their weaknesses.

Annex 7. Muscular Endurance Table.

Muscular Endurance						
Article/ Reference	**Goal of the Study**	**Sample**	**Intervention**	**Methods / ME Measuring Protocol**	**Results of Interest/ Cutoff Values**	**Main Conclusions**
(23)	To investigate whether the test items used in the FSC can differentiate participants from Flemish Top Sport Academies in nine sports, i.e., badminton, basketball, gymnastics, handball, judo, soccer, table tennis, triathlon, and volleyball.	n = 141 elite young male athletes (16.1±0.8 years). Badminton = 12	The participants completed the 22 generic tests of the FSC, consisting of anthropometrical, physical performance and motor coordination measurements, assessed by 11 experienced examiners.	Upper-body strength endurance was measured by a knee pushups and sit-ups test, according to the Test (BOT-2) (85) requiring the athletes to execute as many repetitions as possible in 30 s.	Badminton (n): 43±7	The FSC confirms that elite adolescent boys show differences in generic talent characteristic that distinguish them according to their sport. The FSC can also identify relevant talent characteristics for each sport, which could be used in the purposeful orientation of talented individuals according to their strengths and their weaknesses.

Annex 8. Power Table.

Power						
Article/ Reference	**Goal of the Study**	**Sample**	**Intervention**	**Methods / Power Measuring Protocol**	**Results of Interest/ Cutoff Values**	**Main Conclusions**
(55)	This study investigated the short-term effects of LFCM consumption on DOMS and performance in female badminton players.	n = 7 female badminton players LFCM = 4 Placebo Group = 3 After one week the individuals switched groups.	The participants were randomly assigned to 1 week of LFCM (500 mL) or placebo (water, 500 mL) consumption in a crossover design. They consumed LFCM or water immediately after each training session during 1-week. Performance variables were assessed pre- and post-intervention. In addition, the Visual Analogue Scale was used to assess DOMS before, immediately after, and 24 and 48 h after each training session.	The 3-kg medicine ball throw test and VJ test (Sargent jump) were used to assess the explosive power of upper and lower extremity muscles, respectively. The relative (e.g., adjusted for BM) and maximal power of the lower extremity were evaluated using the Johnson and Bahamonde formula.	3 kg Medicine Ball Throw (m): Baseline: 4.4±0.5 Placebo Post: 5±0.36 LFCM Post: 5.1±0.31 VJ (Max Explosive Power) (w): Baseline: 2402.1±508.6 Placebo Post: 2593±514 LFCM Post: 2716.5±583.8	There were no significant changes in maximum anaerobic power, agility, and maximum handgrip strength. LFCM, as a post-exercise beverage, may help speed recovery in female badminton players leading to increased aerobic, anaerobic and strength performance indices, increased TTE, and decreased muscle soreness and RPE.

Annex 8. Power Table (Continuation).

Power						
Article/ Reference	**Goal of the Study**	**Sample**	**Intervention**	**Methods / Power Measuring Protocol**	**Results of Interest/ Cutoff Values**	**Main Conclusions**
(58)	To assess general and specific lower and upper limb force, shuttlecock velocity, displacement ability, and the anthropometric characteristics of badminton players at 5 skill levels, and to predict individual players' number of points.	n = 83 badminton players Novice = 15 Intermediate = 16 Skilled = 23 Highly Skilled = 14 Elite = 15	The subjects were first divided into one of five groups. Anthropometric measurements of height, BM, BF percentage, and muscle were recorded, along with shuttlecock maximal velocity during smashes. Upper limb power and lower limb force were recorded during jumps and handgrip strength. Players' ability to move quickly around the court was also assessed through an on-court MRSAB test with 4 changes of direction. All variables were combined in a multiple regression model.	All VJ's were recorded using an accelerometric system at a frequency of 500 Hz (Myotest, Sion, Switzerland) during: (a) SJs; (b) CMJs; and (c) with rebounds during a hopping-in-place jumping test with 5 repeated jumps to maximize jump height, reduce ground-contact time, and thus optimize leg stiffness. During each jump, the participants maintained their hands on their hips and performed 2 jumps.	SJ Elite: Height (cm): 40±7.4 Power (w): 50.2±8.2 CMJ Elite: Height (cm): 44±6.9 Power (w): 45.9±9.1	The main findings were that the major contributor to skill level is shuttlecock velocity (r =0.86), the time taken to move during the MRSAB test (r = 0.85) and the SJ height (r = 0.53). Anthropometric factors contribute only a little to the individual score point (2%).
(23)	To investigate whether the test items used in the FSC are able to differentiate participants from Flemish Top Sport Academies in nine sports, i.e. badminton, basketball, gymnastics, handball, judo, soccer, table tennis, triathlon, and volleyball.	n = 141 elite young male athletes (16.1 ± 0.8 years). Badminton = 12	The participants completed the 22 generic tests of the FSC, consisting of anthropometrical, physical performance and motor coordination measurements, assessed by 11 experienced examiners.	To assess explosive leg power, CMJ and SBJ were performed. The participants performed three single CMJ's without arm swing recorded with an OptoJump device (MicroGate, Italy). The highest of three jumps was used for further analysis (0.1 cm). The SBJ is part of the EUROFIT (83) and was measured with an accuracy of 1.0 cm	CMJ (cm): 40.5±3.3 SBJ (cm): 227±18	The FSC confirms that elite adolescent boys show differences in generic talent characteristic that distinguish them according to their sport. The FSC can also identify relevant talent characteristics for each sport, which could be used in the purposeful orientation of talented individuals according to their strengths and their weaknesses.

Annex 8. Power Table (Continuation).

Power						
Article/ Reference	**Goal of the Study**	**Sample**	**Intervention**	**Methods / Power Measuring Protocol**	**Results of Interest/ Cutoff Values**	**Main Conclusions**
(81)	To compare the effects of four weeks of PT training and EMS of knee extensor and ankle plantar flexor muscles on agility, 30-m sprint, lower limb explosive power and jumping ability amongst badminton players.	n = 90 state level badminton players PT = 30 EMS = 30 CG = 30	Pretest-Post-test Design with two ExG's and a CG was used. The PT training was carried out two times/week while the EMS training was four times/week for four weeks The CG did not receive any intervention. All three groups continued their general badminton training throughout the study. Players were assessed for agility, a 30-m sprint, a SBJ, and a VJH before and after four weeks.	SBJ test was used to measure lower limb explosive power. The players stood with both feet on level ground with the point of the shoe at a marked line and arms by the sides. Players were asked to jump as far forward as possible. The measurements were taken in cm from the marked line to the point of heel contact. The best of three jumps was used for analysis. Each player performed a VJH Test. The player stood side onto the wall, keeping both feet on the ground, reaching up with one straight hand and touching the wall with the tip of the middle finger marked with ink. Then they were asked to static squat down, jump as high as possible, and marked the wall with the tip of the middle finger. The best of three trials was used for analysis.	SBJ (cm): PT: 211.8±36.9 EMS: 228.53±13.95 CG: 208.6±16.41 VJH (cm): PT: 46.20±7.22 EMS: 53.80±3.38 CG: 46.70±4.13	PT training showed significant improvement in sprint time and jumping ability, whereas EMS training showed significant Improvement only in jumping ability
(66)	To investigate the relationships between shuttlecock velocity during a badminton forehand smash with and without jump and, strength of upper limb muscles, VJH and to analyse differences in these parameters for each gender.	n = 14 Polish National Badminton Team members Male = 7 Female = 7	This study examined members of the Polish National Badminton Team seven women and seven men. A special torque meter was used to assess the strength of the upper limb muscles. VJ's were performed on a force plate. Shuttlecock velocity was measured using Vicon motion capture system.	Each participant performed nine VJ's on the force plate: three jumps of each kind. The jumping tests realized were the following. CMJ, Spike Jump (SPJ) and Akimbo Countermovement Jump (ACMJ).	ACMJ Height (cm): Male: 45.47±2.00 Female: 30.79 ± 3.53 CMJ Height (cm): Male: 50.24±3.33 Female: 36.46±3.75 SPJ Height (cm): Male: 62.57±2.99 Female: 42.51±1.52	The jump before smash is not used to hit the shuttle from the highest point, but to gain time to correctly prepare the phase of stroke while being in the air.

Annex 8. Power Table (Continuation).

Power						
Article/ Reference	**Goal of the Study**	**Sample**	**Intervention**	**Methods / Power Measuring Protocol**	**Results of Interest/ Cutoff Values**	**Main Conclusions**
(57)	To develop a new sport-specific, repeated-sprint ability test involving 4 changes of direction, namely, the MRSAB test for badminton players, and to determine its validity by comparing the results of 5 different skill levels. It was also to assess the link between the new test and neuromuscular lower limb and physiological variables.	n = 42 novice to elite level badminton players. Elite = 9 Highly Skilled = 9 Skilled = 9 Intermediate = 9 Novice = 6	The participants were separated into 5 groups to perform the MRSAB test at the same time of day, on 2 occasions, separated by at least 48 hours. The best time, mean time, and fatigue index were measured. Heart rate and blood lactate concentration were also recorded to determine the participants' physiological responses to the test.	All VJ's were recorded using an accelerometric system at a frequency of 500 Hz (MyotestÒ; Switzerland) during: (a) SJ; (b) CMJ; and (c) with rebounds during a hopping-in-place jumping test with 5 repeated jumps to maximize jump height, reduce ground contact time, and thus, optimize leg stiffness. During each jump, the participants maintained their hands on their hips and performed 2 jumps. The device calculated performance from flight times. Leg stiffness was calculated by the formula of Dalleau.	SJ Height (cm): Elite: 40.1±9.2 CMJ Height (cm): Elite: 42.6±8.2	The results show that the MRSAB test is valid, because it differentiates between the 5 skill levels for best time, mean time and fatigue index and offers a reliable method for testing badminton players, with no differences between the sessions. Moreover, the link between mean time and neuromuscular variables, such as jump height in squats and countermovements and with VO^2max reveals that this test uses a combination of the anaerobic and aerobic systems, thus, it can be used by trainers either to improve movement ability or increase these physical qualities.
(60)	To Investigate the effects of INT on injury prevention and the performance of professional female badminton athletes.	n = 38 elite male badminton athletes HG = 22 LG = 16	Two groups of athletes took part in an 8-week INT program consisting of four 90-min sessions each week. The asymmetries in movement, physical fitness, and special abilities were tested before and after the intervention.	In the VJ test, the tester uses the Opto Gait Italian intelligent motion analysis system (Optojump, Microgate, Bolzano, Italy). The test starts with the setting of the Vertec in which the standing height of the participant with one arm fully extended upward is taken to set the lowest pane. Participants are required to jump up and touch the highest possible pane. Participants were allowed to swing their arms and bend their knees to simulate the real movement in sports, tested 3 times, and take the highest test record score among them.	HG (cm): Pre: 33.69 ± 3.12 Post: 37.21 ± 2.83 LG (cm): Pre: 35.76 ± 2.28 Post: 38.46 ± 2.08	INT can effectively improve the asymmetry of female badminton athletes' limbs, prevent sports injury, and improve the athlete's performance ability. Athletes in different risk groups have certain differences in the degree of improvement in their motor skills.

Annex 8. Power Table (Continuation).

Power						
Article/ Reference	**Goal of the Study**	**Sample**	**Intervention**	**Methods / Power Measuring Protocol**	**Results of Interest/ Cutoff Values**	**Main Conclusions**
(51)	To assess the reliability of a specific COD test (i.e., "OnCourt COD test") in youth badminton players, evaluate the effect of age on On-Court COD performance, and examine its correlations with linear speed, COD speed, and VJ tests.	n = 42 young badminton players (27 males and 15 females) Under 17 = 21 Under 19 = 21	42 young badminton players were divided into two age groups and took part in assessment routines which took part in two different days. All tests were performed in the same order, using the same testing devices, measurement protocols, and experienced evaluators.	Bilateral and unilateral (e.g., dominant, and non-dominant side) CMJ without an arm swing were performed on an infrared plate Optojump (Microgate, Bolzano, Italy). Players performed the jumps starting in a standing position with their hands on the hips; subsequently, they flexed their knees using a self-selected depth and then jumped as high as possible. Each player performed three maximal CMJs of each type (i.e., bilateral, and unilateral) interspersed with 45s of passive recovery. The highest jump height was recorded for each athlete and used for further analysis.	U19 CMJ (cm): 32.15±5.8 U19 CMJ Dominant (cm): 18.40±4.9 U19 CMJ Non-Dominant (cm): 17.09±4.3	The On-Court COD test is a useful and reliable means to assess COD performance in youth badminton players and it is associated with acceleration, sprint and jump performance.

Annex 9. Reaction Time Table.

Reaction Time						
Article/ Reference	**Goal of the Study**	**Sample**	**Intervention**	**Methods / RT Measuring Protocol**	**Results of Interest/ Cutoff Values**	**Main Conclusions**
(64)	To determine whether carbohydrate ingestion affects badminton performance.	n = 9 male badminton players	All participants performed a Vo²max test on a treadmill (Woodway GmbH) before data collection. This allowed for the identification of participants' Vo²max and MHR in order to determine relative intensity during the experimental trials. The participants then completed two experimental trials separated by one week, in which they consumed 1 L of a 6.4% carbohydrate-electrolyte drink or a similar tasting placebo drink with identical electrolyte composition.	Participants performed a choice reaction time test (NewTest 300, Oulu, Finland). This required the athlete to react to one of two lights and run 5 m in the required direction through timing gates with the time to reach the timing gates being recorded. A familiarization trial was allowed before the five trials were performed. The fastest and slowest times were eliminated, and a mean reaction time was calculated.	Placebo (ms): Pre: 1930±240 Post: 2008±239 Carbohydrate-electrolyte (ms): Pre: 1972±174 Post: 1988±165	The results suggest that only the long serve is influenced by fatigue and carbohydrate tended to prevent the deterioration in performance

Annex 9. Reaction Time Table (Continuation).

Reaction Time						
Article/ Reference	**Goal of the Study**	**Sample**	**Intervention**	**Methods / RT Measuring Protocol**	**Results of Interest/ Cutoff Values**	**Main Conclusions**
(71)	To evaluate the reproducibility and validity of a newly developed Badminton Reaction Inhibition Test (BRIT).	n = 24 Dutch male badminton players Elite Group = 15 Non-Elite Group = 9	A two-fold design was used to evaluate the reproducibility and validity of the test. First, the reproducibility of the assessment of badminton-specific reaction time and inhibitory control was examined by means of a test-retest design. The time between the initial test and retest ranged from two to three weeks. In the second part of the study, the validity of all four components of the test was evaluated. The test was examined on its ability to discriminate between elite and non-elite players and on the relationship between test results and the national ranking.	Testing was conducted under supervision of one researcher with help of two other experienced test leaders and took place during the Dutch National Championships or prior to a training session. During the testing session, the players executed the BRIT and filled in a questionnaire about badminton related activities over the past eight years, including hours of training per week and starting age.	Elite: Badminton Specific Reaction Time (BSRT) (ms): 433±93 Forehand (ms): 427±107 backhand (ms): 438±100	Reproducibility and validity of inhibitory control assessment was not confirmed; however, the BRIT appears a reproducible and valid measure of reaction time in badminton players. Reaction time measured with the BRIT may provide input for training programs aiming to improve badminton players' performance.
(68)	To compare the effects of Ballistic Six training and TheraBand exercises on shoulder strength, agility, speed, and function in novice badminton players.	n = 40 subjects of both genders who play badminton for more than a year.	The participants were randomized into two groups, Group A (Ballistic Six Exercise group) and Group B (TheraBand exercise group). Assessments done were the SMBT for shoulder strength, CKUCEST for agility, PTT for speed and KJOC for shoulder function. Assessments were done at baseline, post 8 weeks of training and at the end of 6 months.	The PTT was designed to assess the athletes' upper extremity movements' quickness. It is a response evaluation that uses an alternative tapping motion to evaluate upper extremity response timing, hand-eye quickness, as well as synergy	Ballistic Six Exercise Group (sec): Pre: 15.16±1.25 Post: 7.96±0.95 Follow Up: 6.46±0.62 TheraBand Exercise Group (sec): Pre: 15.18±1.26 Post: 9.53±1.37 Follow Up: 7.86±1.03	The study concluded that adding of Ballistic Six PT training for novice badminton players would increase the shoulder strength, agility, speed, and function than the TheraBand exercises.

Annex 10. Speed Table.

Speed						
Article/ Reference	**Goal of the Study**	**Sample**	**Intervention**	**Methods / Speed Measuring Protocol**	**Results of Interest/ Cutoff Values**	**Main Conclusions**
(55)	This study investigated the short-term effects of LFCM consumption on DOMS and performance in female badminton players.	n = 7 female badminton players LFCM = 4 Placebo Group = 3 After one week the individuals switched groups.	The participants were randomly assigned to 1 week of LFCM (500 mL) or placebo (water, 500 mL) consumption in a crossover design. They consumed LFCM or water immediately after each training session during 1-week. Performance variables were assessed pre- and post-intervention. In addition, the Visual Analogue Scale was used to assess DOMS before, immediately after, and 24 and 48 h after each training session.	Anaerobic power was measured using the Running Anaerobic Sprint Test (RAST).	Max Anaerobic Power (W): Baseline: 266.1±56.4 Post LFCM: 252.5±64.6 Post Placebo: 234.1±37.4 Average Anaerobic Power (W): Baseline: 195±43.9 Post LFCM: 200.1±41.1 Post Placebo: 184.01±30.3	There were no significant changes in maximum anaerobic power, agility, and maximum handgrip strength. LFCM, as a post-exercise beverage, may help speed recovery in female badminton players leading to increased aerobic, anaerobic and strength performance indices, increased TTE, and decreased muscle soreness and RPE.
(23)	To investigate whether the test items used in the FSC can differentiate participants from Flemish Top Sport Academies in nine sports, i.e., badminton, basketball, gymnastics, handball, judo, soccer, table tennis, triathlon, and volleyball.	n = 141 elite young male athletes (16.1 ± 0.8 years). Badminton = 12	The participants completed the 22 generic tests of the FSC, consisting of anthropometrical, physical performance and motor coordination measurements, assessed by 11 experienced examiners.	Two maximal sprints of 30 m with split times at 5 m and 30 m were used to assess speed. The recovery time between each sprint was set at 2 min. The fastest time needed to cover distances was used for analysis (84). The sprint test was recorded with MicroGate Racetime2 chronometry and Polifemo Light photocells at an accuracy of 0.001 s (MicroGate, Italy).	Badminton (sec): 30m: 4.358±0.182 5m: 1.046±0.066	The FSC confirms that elite adolescent boys show differences in generic talent characteristic that distinguish them according to their sport. The FSC can also identify relevant talent characteristics for each sport, which could be used in the purposeful orientation of talented individuals according to their strengths and their weaknesses.

Annex 10. Speed Table (Continuation).

Speed						
Article/ Reference	**Goal of the Study**	**Sample**	**Intervention**	**Methods / Speed Measuring Protocol**	**Results of Interest/ Cutoff Values**	**Main Conclusions**
(81)	To compare the effects of four weeks of PT training and EMS of knee extensor and ankle plantar flexor muscles on agility, 30-m sprint, lower limb explosive power and jumping ability amongst badminton players.	n = 90 state level badminton players PT = 30 EMS= 30 CG = 30	Pretest-Posttest Design with two ExG's and a CG was used. The PT training was carried out two times/week while the EMS training was four times/week for four weeks The CG did not receive any intervention. All three groups continued their general badminton training throughout the study. Players were assessed for agility, a 30-m sprint, a SBJ, and a VJH before and after four weeks.	Thirty-meter sprint test was used for running speed. Players were allowed for a warm-up and total recovery time before actual testing. The front foot was placed on or behind the start line. When the tester whistled, the players started to sprint, and the time was recorded nearest to 0.01 s using a stopwatch as the players crossed the 30-m line. The best of three trials was used for analysis.	PT (sec): 4.95±0.29 EMS (sec): 4.43±0.24 CG (sec): 4.56±0.15	PT training showed significant improvement in sprint time and jumping ability, whereas EMS training showed significant Improvement only in jumping ability
(67)	To develop a BST, which includes a random movement pattern comparable with real game situations and evaluate the reproducibility and specificity of the developed test. It was the intention that the BST should be able to differentiate between elite, less skilled, and non-badminton players and with test reproducibility comparable with simple sprint tests.	n = 61 Healthy male subjects Elite = 20 Skilled = 21 Non-Badminton Players = 20	Day-to-day variation in elite players was assessed, and specificity of the test was evaluated by comparing 30-m sprint performance and time to complete the BST in 20 elite players, 21 skilled players, and 20 age-matched physical active subjects (non-badminton players).	30m Sprint Test: The subject performed active warm-up for 15 min (running and stretching activities) before completing 3–4 habituation trials at submaximal intensities. Subsequently, the subject completed 30-m sprints from a standing start position, with the start and finish time recorded by photocells, and the time for 30-m mark stored electronically (Newtest Power Timer System, Oulu, Finland). The fastest sprint time was used as the test result of each of the subject's 30-m sprint performance. BST: The test starts in the centre of the court and consists of 5 maximal actions to sensors located in each of the 4 corners of the court. The 20 actions are performed in randomized order as dictated by computer screen shots displayed 1 second after completion of the previous action.	Badminton Speed Test (sec): Elite: 32.3±1.1 Skilled: 34.1±2.0 30m Speed Test: Not Reported	The BST may be valuable for evaluation of short-term maximal movement speed in badminton players. Thus, the BST seems to be sport specific, as it may discriminate between groups (elite, less trained players, and non-badminton players) with similar sprinting performance, and the low test-retest variation may allow for using the BST to evaluate longitudinal changes, for example, training effects or seasonal variations.

Annex 10. Speed Table (Continuation).

Speed						
Article/ Reference	**Goal of the Study**	**Sample**	**Intervention**	**Methods / Speed Measuring Protocol**	**Results of Interest/ Cutoff Values**	**Main Conclusions**
(60)	To Investigate the effects of INT on injury prevention and the performance of professional female badminton athletes.	n = 38 elite male badminton athletes HG = 22 LG = 16	Two groups of athletes took part in an 8-week INT program consisting of four 90-min sessions each week. The asymmetries in movement, physical fitness, and special abilities were tested before and after the intervention.	The speed test 30 m sprint test uses a Brower Timing Systems speed tester (Draper, UT, USA). The subjects used a standing start at the designated starting line and started running on their own when they were ready. The best result was recorded from 2 tests. The accuracy of the test time was 0.01 s. Before the formal test, the participants were required to warm up for 15 min, wear a heart rate monitor, and only start the second test when the real-time heart rate recovery was lower than 100 bpm.	HG (sec): Pre: 4:26±0:13 Post: 4:21±0:08 LG (sec): Pre: 4:23±0:14 Post: 4:12±0:13	INT can effectively improve the asymmetry of female badminton athletes' limbs, prevent sports injury, and improve the athlete's performance ability. Athletes in different risk groups have certain differences in the degree of improvement in their motor skills.
(51)	To assess the reliability of a specific COD test (i.e., "OnCourt COD test") in youth badminton players, evaluate the effect of age on On-Court COD performance, and examine its correlations with linear speed, COD, speed, and VJ tests.	n = 42 young badminton players (27 males and 15 females) Under 17 = 21 Under 19 = 21	42 young badminton players were divided into two age groups and took part in assessment routines which took part in two different days. All tests were performed in the same order, using the same testing devices, measurement protocols, and experienced evaluators.	Time during a 20m dash (with 5, 10, 15 and 20m split times) in a straight line was measured by means of single beam photocell gates placed 1.0m above the ground level (Microgate, Bolzano, Italy). Each sprint was initiated 50cm behind the photocell gate, which then started a digital timer. Each player performed three maximal 20m sprints with at least 2min of passive recovery between the three trials. The best performance was recorded for further analysis.	Under 19 (sec): 5m: 1.09±0.07 10m: 1.81±0.1 15m: 2.51±0.2 20m: 3.20±0.3	The On-Court COD test is a useful and reliable means to assess COD performance in youth badminton players and it is associated with acceleration, sprint and jump performance.

Annex 11. Strength Table.

Strength						
Article/ Reference	**Goal of the Study**	**Sample**	**Intervention**	**Methods / Strength Measuring Protocol**	**Results of Interest/ Cutoff Values**	**Main Conclusions**
(52)	To investigate the effect of combined balance and PT training on the COD performance of badminton athletes.	n = 16 PB group = 8 PT group = 8	Two groups of athletes took part in a balance combined with PT training or only PT training for 6 weeks. All participants were tested to assess the COD ability before and after the training period.	The test is applied to evaluate how athletes perform during PT by measuring the muscle-tendon stress and their reactive jump capacity so that their ability to quickly and effectively moving through the strength-shortening cycle is demonstrated. RSI was measured using depth jump from a 30 cm PT take-off velocity derived from their respective force-time data. Later, the RSI score was calculated using the highest jump height recorded from three trials using the below formula: RSI = Jump height / ground contact time	Pre: PB group: 1.27±0.14 PT Group: 1.22±0.12 Post: PB group: 1.50±0.12 PT Group: 1.35±0.15	Combined training induced an overall better adaptation for the SEMO TEST, the 5-0-5 COD test, the YBT, and the RSI test than PT training. Considering that balance training is relatively time-efficient (20 min in the current study), it is suggested that adding such exercises would allow optimal training adaptations for badminton players.
(55)	This study investigated the short-term effects of LFCM consumption on DOMS and performance in female badminton players.	n = 7 female badminton players LFCM = 4 Placebo Group = 3 After one week the individuals switched groups.	The participants were randomly assigned to 1 week of LFCM (500 mL) or placebo (water, 500 mL) consumption in a crossover design. They consumed LFCM or water immediately after each training session during 1-week. Performance variables were assessed pre- and post-intervention. In addition, the Visual Analogue Scale was used to assess DOMS before, immediately after, and 24 and 48 h after each training session.	A handgrip dynamometer (Jamar Hydraulic HHD, Warrenville, IL, USA) was used to measure the maximal isometric grip strength.	Baseline (kg): 22.8±4.7 Placebo (kg): 24±4.8 LFCM (kg): 25.5±3	There were no significant changes in maximum anaerobic power, agility, and maximum handgrip strength. LFCM, as a post-exercise beverage, may help speed recovery in female badminton players leading to increased aerobic, anaerobic and strength performance indices, increased TTE, and decreased muscle soreness and RPE.

Annex 11. Strength Table (Continuation).

Strength						
Article/ Reference	**Goal of the Study**	**Sample**	**Intervention**	**Methods / Strength Measuring Protocol**	**Results of Interest/ Cutoff Values**	**Main Conclusions**
(69)	To analyse peripheral BDNF levels and psychophysiological parameters in youth badminton athletes during the season and to determine the relationship between variables.	n = 14 young badminton athletes (age = 16.8±1.8 years) Female = 9 Male = 5	All participants were assessed over the season (preseason, middle season, and final season). sBDNF was determined during the preseason and final season. Sleep time, total physical activity, and time in vigorous activity were measured using an accelerometer. The FFM, SMM, FM, handgrip strength, VO^2max, and dietary intake were evaluated during the season. Cognitive tasks and mood, were also evaluated.	The Jamar dynamometer set was used with the subjects in a sitting position, according to the procedures used by (86). The volunteers repeated the procedure 3 times, with a 1-min rest between sets, and the best value for each arm was recorded.	Female Dominant (kg): Pre: 28.2±5.1 Middle: 28.3±8.0 Final: 29.2±4.1 Female Nondominant (kg): Pre: 23.6±5.5 Middle: 21.0±5.8 Final: 21.6±5.9 Male Dominant (kg): Pre: 36.6±5.5 Middle: 34.4±1.5 Final: 36.4±4.3 Male Nondominant (kg): Pre: 32.8±5.3 Middle: 30.0±4.7 Final: 33.2±6.8	Youth badminton athletes decreased their sBDNF levels, sleep time, carbohydrate, and calorie intake across the season. The athletes improved in cognitive function; however, only the females improved in body composition, and the males improved their VO^2max in the middle season. The sBDNF levels were positively correlated with the VO^2max in the preseason, and no correlations were observed among the sBDNF and psychological parameters, sleep time, and sport performance during the season.

Annex 11. Strength Table (Continuation).

Strength						
Article/ Reference	**Goal of the Study**	**Sample**	**Intervention**	**Methods / Strength Measuring Protocol**	**Results of Interest/ Cutoff Values**	**Main Conclusions**
(58)	To assess general and specific lower and upper limb force, shuttlecock velocity, displacement ability, and the anthropometric characteristics of badminton players at 5 skill levels, and to predict individual players' number of points.	n = 83 badminton players Novice = 15 Intermediate = 16 Skilled = 23 Highly Skilled =14 Elite = 15	The subjects were first divided into one of five groups. The number of points scored for each player performing tournaments (excluding novices) during the entire season was used as a continuous and dependent variable after logarithmic transformation for correlational study. Anthropometric measurements of height, BM, BF percentage, and muscle were recorded, along with shuttlecock maximal velocity during smashes. Upper limb power and lower limb force were recorded during jumps and handgrip strength. We also assessed players' ability to move quickly around the court through an on-court MRSAB test with 4 changes of direction. All variables were combined in a multiple regression model.	Handgrip and fingertip strength were assessed using an electronic HHD (Camry, Rosemead, CA, USA). To measure handgrip strength, 3 recordings of maximal strength were taken in a neutral forearm position with the hand holding the racket. The intraclass correlation was measured at 0.95. To measure fingertip strength, subjects were asked to perform a maximal voluntary contraction over a 5-second period in the following position: the subject was sitting on a chair with one arm at 45° from the trunk, the elbow positioned on the table with a 90° angle between the arm and forearm and with the whole of the palm of the hand in contact with the table. Only the distal phalanx was in contact with the dynamometer force bar. The thumb was pressed onto the other side of the hand.	Novices (kg): 40.4±6 Intermediates (kg): 41.1±6.8 Skilled (kg): 42.5±5.7 Highly Skilled (kg): 44.8±5.8 Elite (kg): 48.2±5.7	The main findings were that the major contributor to skill level is shuttlecock velocity (r =0.86), the time taken to move during the MRSAB test (r = 0.85) and the SJ height (r = 0.53). Anthropometric factors contribute only a little to the individual score point (2%).

Annex 11. Strength Table (Continuation).

Strength						
Article/ Reference	**Goal of the Study**	**Sample**	**Intervention**	**Methods / Strength Measuring Protocol**	**Results of Interest/ Cutoff Values**	**Main Conclusions**
(66)	To investigate the relationships between shuttlecock velocity during a badminton forehand smash with and without jump, strength of upper limb muscles, VJH, and to analyse differences in these parameters for each gender.	n = 14 Polish National Badminton Team members Male = 7 Female = 7	This study examined members of the Polish National Badminton Team seven women and seven men. A special torque meter was used to assess the strength of the upper limb muscles. VJ's were performed on a force plate. Shuttlecock velocity was measured using Vicon motion capture system.	The maximal joint torque of the flexors and extensors of the elbow and shoulder were measured under isometric conditions, using a special torque meter (Institute of Sport, Poland; type SMS1 (upper extremities)). During the measurements of elbow flexors and extensors, the subject was in a sitting position, with his arm and forearm positioned to a 90° angle and placed on the armrest, and with the trunk stabilized. The joint torque of the shoulder flexors and extensors was also measured in a sitting position. The flexion angle was set at 70° and the extension angle was 50°. The maximal extension of the elbow was accepted as 0°. For the shoulder joint, the position of the arm along the side of the body was taken as 0°. The axis of rotation during joint torque measurements corresponded to the axis of rotation of the torque meter. Joint torques of the right and left limb were measured separately, always in the order flexion-extension. The subjects were instructed to develop maximal possible force.	Male: Left Upper Extremity (Nm/kg): 3.30±0.21 Right Upper Extremity (Nm/kg): 3.56±0.31 Female: Left Upper Extremity (Nm/kg): 2.48±0.21 Right Upper Extremity (Nm/kg): 2.67±0.20	The jump before smash is not used to hit the shuttle from the highest point, but to gain time to correctly prepare the phase of stroke while being in the air.

Annex 11. Strength Table (Continuation).

Strength						
Article/ Reference	**Goal of the Study**	**Sample**	**Intervention**	**Methods / Strength Measuring Protocol**	**Results of Interest/ Cutoff Values**	**Main Conclusions**
(63)	To confirm the correlation between racket velocity during the forehand smash movements with shoulder extensor strength and internal rotator strength in the neutral and abducted positions.	n = 14 Collegiate badminton players.	Measurements performed were shoulder strength, using torque calculated from the upper extremity length and the isometric force, and racket velocity during the forehand smash movements.	The shoulder extensor strength and internal rotator strength were measured in the neutral and abducted positions.	Extension Force – Maximum shoulder abduction (n): 96.1±41.6 Extension Torque - Maximum shoulder abduction (Nm): 58.5±28.1 Extension Force – Neutral Position (n): 66.3±14.4 Extension Torque – Neutral Position (Nm): 40.0±11.1 IR Force – Abducted and ER Position (n): 83.3±30.3 IR Torque – Abducted and ER Position (Nm): 26.8±11.9 IR Force – Neutral Position (n): 117.7±25.5 IR Torque – Neutral Position (Nm): 37.2±9.4	The shoulder internal rotator strength in the abducted external rotated position are suitable measurements for evaluating badminton players.

Annex 11. Strength Table (Continuation).

Strength						
Article/ Reference	**Goal of the Study**	**Sample**	**Intervention**	**Methods / Strength Measuring Protocol**	**Results of Interest/ Cutoff Values**	**Main Conclusions**
(70)	To examine Acromio-Humeral Distance (AHD) and shoulder isometric strength for ER and IR in national elite badminton players.	n = 7 Elite badminton players with asymptomatic shoulders from the Danish national badminton team. Male = 5 Female = 2	Shoulder AHD, isometric strength in ER and IR were bilaterally assessed with ultrasonography and an HHD.	Measurements of shoulder strength were obtained with an HHD (J-Tech Power Track® dynamometer, JTECH Medical, Salt Lake City, UT, USA). For the ER-strength test, the player externally rotated the shoulder against the HHD, while the HHD was located proximal to the ulnar styloid processus. For the IR-strength test, the player internally rotated the shoulder against the HHD, while the HHD was located proximal to the ulnar styloid processus. The isometric "make test" consisted of a 5–6 s maximal effort by the subject. The HHD was calibrated prior to each test. One examiner performed all the tests.	ER Strength Dominant (Nm): 44±3 ER Strength Nondominant (Nm): 44±4 IR Strength Dominant (Nm): 54±3 IR Strength Nondominant (Nm): 48±3	This preliminary study demonstrates that shoulder ER strength is strongly associated with AHD size, largely reflecting supraspinatus tendon-muscle hypertrophy because of sport-specific adaptation in national elite badminton players with asymptomatic shoulders. These novel data also suggest that habitual loading of the shoulder improves the supraspinatus tendon size, which may lower the mechanical stress and potentially reduce the risk of injury. These warrants strengthening the shoulder external rotators as a potential strategy to reduce the risk of future shoulder injury.

Annex 11. Strength Table (Continuation).

Strength						
Article/ Reference	**Goal of the Study**	**Sample**	**Intervention**	**Methods / Strength Measuring Protocol**	**Results of Interest/ Cutoff Values**	**Main Conclusions**
(49)	To assess the occurrence of muscle damage after a simulated badminton match and its influence on physical and haematological parameters.	n = 16 Competitive male badminton players	Before and just after a 45-min simulated badminton match, maximal isometric force and badminton specific running/movement velocity were measured to assess muscle fatigue. Blood samples were also obtained before and after the match.	A load cell (Isocontrol; ATEmicro, Madrid, Spain) was used to assess the maximal isometric voluntary contraction. The subjects stood with both feet on the floor and with a knee angle of 140°. The bar was placed at a height where the subjects could hold it with their upper limbs extended to the floor with their back straight, and it was attached to a chain at the end. The chain was connected to a load cell that was fixed to the ground. The chain length allowed the subjects to maintain the knee angle of 140° during the exercise. Knee flexion was monitored with a manual goniometer. The load cell force signals were sampled at 200 Hz. Each subject performed two repetitions with a 2-min rest period between them. The signals were analysed offline selecting the subject's best trial.	Pre (N): 1263±245 Post (N): 1290±240	A simulated badminton match modified haematological parameters of whole blood and serum blood that indicate the occurrence of muscle fibre damage. However, the level of muscle damage did not produce decreased muscle performance.
(68)	To compare the effects of Ballistic Six training and Theraband exercises on shoulder strength, agility, speed, and function in novice badminton players.	n = 40 subjects of both genders who play badminton for more than a year.	The participants were randomized into two groups, Group A (Ballistic Six Exercise group) and Group B (TheraBand exercise group). Assessments done were the SMBT for shoulder strength, CKUCEST for agility, PTT for speed and KJOC for shoulder function. Assessments were done at baseline, post 8 weeks of training and at the end of 6 months.	(SMBT is a common tool for assessing bilateral upper limb strength in elite athletes, senior persons, college as well as university graduates, warriors, fit nonathletic populations, even kids. Despite this, studies on link between SMBT, strength and power attributes, particularly among overhead athletes, is limited.	Ballistic Six Exercise Group: Pre: 301.50±6.04 Post: 335.15±7.02 TheraBand Exercise Group: Pre: 303.40±5 Post: 329.29±3.75	The study concluded that adding of Ballistic Six PT training for novice badminton players would increase the shoulder strength, agility, speed, and function more than the TheraBand exercises.

Annex 11. Strength Table (Continuation).

Strength						
Article/ Reference	**Goal of the Study**	**Sample**	**Intervention**	**Methods / Strength Measuring Protocol**	**Results of Interest/ Cutoff Values**	**Main Conclusions**
(65)	To compare bilateral absolute and relative shoulder extension-flexion peak moments of volleyball, handball, underwater hockey, and badminton players and to determine whether the decline in the average moment, power, and work measures were consistent with observed bilateral peak moment relationships.	n = 44 Healthy male athletes Badminton = 11	All participants were first evaluated in regard to anthropometric parameters. After the anthropometric evaluation, participants then proceeded to be tested using a dynamometer to compare bilateral absolute and relative shoulder extension-flexion peak moments.	Participants were tested on Humac Norm CSMI Cybex isokinetic dynamometer in the supine position and were encouraged throughout the test. Gravity correction was performed before the test. Stabilization straps were placed over the pelvis and chest, and participants positioned their arms across their chests during familiarization and testing. Following 10 sub-maximal warm-up contractions of the shoulder muscles, subjects were instructed to perform 5 maximal concentric shoulder extension-flexion movements at 60◦/s. These efforts were recorded bilaterally.	Ex_R (Nm): 85.80±8.83 Ex_L (Nm): 87.87±14.63 Fl_R (Nm): 58.33±9.46 Fl_L (Nm): 52.97±9.34 Dominant Extension vs Non-Dominant Extension Ratio (DENDE) (%): 11.57±12.13 Dominant Flexion vs Non-Dominant Flexion Ratio (DENDF) (%): 9.91±13.11	Peak moment only measurements could be inadequate to determine strength discrepancies among different sports branches and the assessment of the declines in the average moment, work and power parameters between the sets may be more beneficial for the examination of shoulder strength characteristics in athletes.

Annex 11. Strength Table (Continuation).

Strength						
Article/ Reference	**Goal of the Study**	**Sample**	**Intervention**	**Methods / Strength Measuring Protocol**	**Results of Interest/ Cutoff Values**	**Main Conclusions**
(72)	Exploring the isokinetic work ratios of eccentric antagonist/concentric agonist shoulder rotators in the late cocking and deceleration phases of a forehand overhead smash in badminton players. Comparing the work ratios between dominant and nondominant shoulders.	n = 25 Skilled men who play badminton at club level	All participants were measured for concentric and eccentric isokinetic work of shoulder IR and ER on both upper extremities at 120°/s.	Bilateral isokinetic work ratios for eccentric IR/concentric ER between 60° and 90° of shoulder ER were calculated to denote strength profile in the late cocking phase of the badminton smash. Work ratios for eccentric ER/concentric IR between 10° ER and 30° IR were calculated to denote strength profile in the deceleration phase of the badminton smash. The respective work ratios were compared between both shoulders.	Dominant (j/kg): Eccentric IR/60° to 90° of ER: 0.19±0.06 Concentric ER/60° to 90° of ER: 0.11±0.03 Eccentric ER/10° of ER to 30° of IR: 0.31±0.06 Concentric IR/10° of ER to 30° of IR: 0.29±0.05 Nondominant (j/kg): Eccentric IR/60° to 90° of ER: 0.14±0.04 Concentric ER/60° to 90° of ER 0.11±0.02 Eccentric ER/10° of ER to 30° of IR: 0.31±0.06 Concentric IR/10° of ER to 30° of IR: 0.24±0.04	The work ratios of eccentric antagonist/concentric agonist are different between dominant and nondominant shoulders of skilled badminton players. Rehabilitation for injuries of these athletes should aim at developing the optimal antagonist/agonist work ratios to return them to this sport

Annex 12. Request for authorization to apply a physical fitness assessment protocol in the Portuguese national badminton team training camp to be held in February 2024

Pedido de autorização para aplicação de protocolo de avaliação da condição física no estágio da seleção nacional portuguesa de badminton a realizar em fevereiro de 2024

Exmo. Sr. Presidente da Federação Portuguesa de Badminton, Horácio Miranda Ornelas Bento de Gouveia,

O meu nome é André Pito, sou jogador de badminton e estudante do 2º ano do mestrado em Atividade Física e Saúde na Escola Superior de Desporto de Rio Maior. Como parte fundamental deste 2º ano estou a elaborar uma tese de mestrado designada de "Condição Física e Desempenho Desportivo em Atletas de Badminton: Avaliação de Marcadores da Condição Física e a sua relação com o Desempenho Desportivo no Badminton", sob orientação do Professor Doutor Nuno Pimenta e Professor Jorge Cação.

Estou neste momento a preparar a recolha de dados sobre a Condição Física (Resistência Cardiovascular; Agilidade; Composição Corporal; Força Explosiva) em atletas séniores portugueses de badminton da categoria absoluta. Para o efeito, será necessário aplicar os respetivos testes para avaliação da Condição Física. Deste modo, caso exista abertura e interesse por parte da Federação Portuguesa de Badminton, venho por este meio solicitar a vossa autorização. Creio que o cenário mais apropriado para realizar as recolhas seria num estágio de seleção nacional de badminton, em fevereiro de 2024. Neste sentido, tenho estado em conversações com o selecionador nacional Diogo Silva e com o preparador físico da seleção nacional José Eduardo Nunes em relação à viabilidade e possibilidade de aplicar o protocolo de avaliação pensado para o estudo que irá integrar a minha tese de mestrado.

Posto isto, venho por este meio formalmente solicitar autorização para aplicar o protocolo de avaliação da condição física, em articulação com a Equipa Técnica Nacional, com atletas da Seleção Nacional no estágio das seleções nacionais que decorre em fevereiro de 2024.

Agradeço desde já a atenção e fico a aguardar uma resposta.

Com os melhores cumprimentos,
André Pito

14 de novembro de 2023

Annex 13. Declared Informed Consent delivered to the athletes.

POLITÉCNICO
DE SANTARÉM

POLITÉCNICO
DE SANTARÉM
ESCOLA SUPERIOR
DE DESPORTO
DE RIO MAIOR

CONSENTIMENTO INFORMADO ESCLARECIDO E LIVRE PARA INVESTIGAÇÃO CIENTÍFICA (De acordo, com a Declaração de Helsínquia e a Convenção de Oviedo)

Este documento, designado Consentimento Informado Esclarecido e Livre, dado por escrito, contém informação relevante em relação ao estudo para o qual foi abordado/a, bem como o que expectável acontecer, se decidir participar no mesmo. Leia atentamente toda a informação aqui contida. Deve sentir-se absolutamente livre para colocar qualquer questão, assim como para discutir com terceiros a decisão da sua participação neste estudo.

Título do Estudo: "Caracterização e Importância de Marcadores da Condição Física em Atletas de Badminton Portugueses de Elite"

O presente estudo desenvolve-se no âmbito da realização da Dissertação de Mestrado em Atividade Física e Saúde da Escola Superior de Desporto de Rio Maior. O orientador da presente dissertação é o Prof. Doutor Nuno Pimenta docente e diretor da Escola Superior de Desporto de Rio Maior, investigador do Centro Interdisciplinar de Performance Humana da Faculdade de Motricidade Humana e do Centro de Investigação Interdisciplinar em Saúde da Universidade Católica Portuguesa. O coorientador da mesma é o Prof. Jorge Cação, docente da Escola Superior de Desporto de Rio Maior.

Os objetivos deste estudo é caracterizar o atleta senior de elite português de badminton relativamente a quatro marcadores da condição física (Agilidade; Composição Corporal; Potência; Resistência Cardiovascular) e analisar a ligação entre o seu desempenho nestes marcadores e o seu desempenho desportivo (ranking nacional). As recolhas serão realizadas no decorrer do estágio da seleção nacional de seniores e sub-23, a decorrer entre os dias 12 a 16 de fevereiro de 2024

Não estão previstas quaisquer despesas pessoais para os participantes no que toca a deslocações ou contrapartidas. Também não há compensação financeira relacionada à sua participação no estudo.

O presente estudo foi submetido e aprovado pela comissão de Ética da Escola Superior de Desporto de Rio Maior.

Annex 13. Declared Informed Consent delivered to the athletes (Continuation).

POLITÉCNICO
DE SANTARÉM

POLITÉCNICO
DE SANTARÉM
ESCOLA SUPERIOR
DE DESPORTO
DE RIO MAIOR

A participação neste estudo é confidencial. Os seus dados pessoais serão de uso exclusivo para o presente estudo, sendo sempre tratados por pessoal autorizado vinculado ao dever de sigilo e confidencialidade. Os dados não serão registados em quaisquer circunstâncias

Além de confidencial, a participação no estudo é estritamente voluntária: pode escolher livremente participar ou não participar. Se tiver escolhido participar, pode interromper a participação e retirar o consentimento para o tratamento dos seus dados pessoais em qualquer momento, sem ter de prestar qualquer justificação. A retirada de consentimento não afeta a legalidade dos tratamentos anteriormente efetuados com base no consentimento prestado.

Se em qualquer etapa do estudo, surgirem questões, terá acesso ao investigador responsável pelo estudo durante todo o estágio de modo a esclarecer as mesmas.

Declaro ter lido e compreendido o consentimento informado esclarecido e livre para investigação científica e estou consciente do que esperar quanto á minha participação no projeto ou estudo "Caracterização e Importância de Marcadores da Condição Física em Atletas de Badminton Portugueses de Elite". Tive a oportunidade de colocar todas as questões e as respostas esclareceram todas as minhas dúvidas. Assim, aceito voluntariamente participar neste estudo. Foi-me dada uma cópia deste documento.

________________ **Nome do participante**	________________ **Assinatura do participante**
___/___/___ **Data**	
________________ **Nome do representante legal do participante** (se aplicável)	________________ **Assinatura do representante legal do participante** (se aplicável)
________________ **Grau de relação com o participante** (se aplicável)	

Annex 13. Declared Informed Consent delivered to the athletes (Continuation).

POLITÉCNICO
DE SANTARÉM

POLITÉCNICO
DE SANTARÉM
ESCOLA SUPERIOR
DE DESPORTO
DE RIO MAIOR

Os aspetos mais importantes deste estudo foram explicados ao participante ou ao seu representante, antes de solicitar a sua assinatura. Uma cópia deste documento ser-lhe-á fornecida. Se achar que algo está incorreto ou que não está claro, não hesite em solicitar mais informações.

André Rafael de Cabrita Pito 961548295 Andrerafa9@hotmail.com	André Rafael de Cabrita Pito
Nome e contacto da pessoa que pede o consentimento	**Assinatura da pessoa que pede o consentimento**

18/12/2023

Data

Annex 14. Biosocial Questionnaire applied to the subjects.

POLITÉCNICO
DE SANTARÉM

POLITÉCNICO
DE SANTARÉM
ESCOLA SUPERIOR
DE DESPORTO
DE RIO MAIOR

Questionário Biossocial

Nome:

Idade:

Data de Nascimento:

Sexo:

Profissão (Se estudante indique neste campo):

Estado Civil:

Anos de Prática de Badminton:

Volume de Treino de Badminton Semanal (Nº de sessões e duração de cada sessão):