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Rui António de Almeida Duarte Fernandes

SPORTS SPECIALISATION IN YOUNG MALE KAYAKERS:

STUDYING THE YOUNG ATHLETE, SPORTS SELECTION PROCESS, PERFORMANCE, AND EQUIPMENT SETUP.

Thesis for the degree of Doctor of Sport Sciences in the branch of Sports Training supervised by PhD Professor Beatriz Branquinho Gomes and PhD Professor Fernando Alacid Cárceles, submitted to the Faculty of Sport Sciences and Physical Education of the University of Coimbra.

August of 2023

Faculty of Sport Sciences and Physical Education

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“Adversity is the state in which man most easily becomes acquainted with himself, being especially free of admirers then.”

(John Wooden)

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Abstract

The main purpose of this Thesis is to better understand the performance of young canoeists, in the different stages of their maturational and sporting development, clearly identifying the explanatory qualities of their competitive success whether they are related to maturational, anthropometric or equipment aspects. Trying to offer orientation guides for coaches and athletes based on scientific evidence that help decision making, whether in the creation of competitive programs, training, kayakers physical and performance evaluation or in the adequate selection of equipment setup.

The current Thesis is written in manuscripts and is organised into nine chapters. Chapter I contains a general introduction, while Chapter II describes in general the methods and procedures adopted in the different studies, including the statistical techniques used. Chapter III focusses on validating a unit with GPS and an accelerometer device developed for field team sports but commonly used by coaches in kayaking and canoeing, which will later facilitate the evaluation of performance in competition and training. Results suggested high agreement showed between GPS-Acc and video analysis results suggesting the GPS-Acc unit is a valuable and accurate solution to assess time and velocity variables, and in terms of the SR assessment, it could have been even more reliable than the video analysis due to the high rate of data analysis. This validation was fundamental in simulated race performance analysis in study 4 (Chapter VI). Chapter IV includes a study focussing on the kayaking experience, the maturity status, and its implication in kayaking performance. The results seem to suggest that the best performances are obtained by more biologically mature kayakers with larger bodies and more years of specific practise, for both U14 and U16. Chapter V comprises a study that investigates the young kayaker's maturity status and includes data on the Relative Age and the. Data showed that the Constituent Year Effects and maturity status seem to influence performance in U16. Regarding Relative Age Effect, despite the fact that no statistically significant differences were found in the total sample, or the two categories assessed, a substantial part of the ten best kayakers in each age group were born between January and June and were early maturers. Chapter VI contains an investigation through which, by analysing several variables, an attempt is made to find an adequate evaluation battery for the age group, also trying to understand the importance of the stroke rate for the performance of young kayakers. The results of this study indicate that a specific evaluation battery for U14 must include the water shoulder distance, the shuttle run test, and the Balance Error Scoring System test, and for U16, the water-shoulder distance, the pull-up test and the sit-up test. Additionally, an increase in SR is associated with better performance performances, in youth kayaking, both for 200 and 500 m, mainly in the age category U16. Chapter VII focusses on creating predictive equations to determine the ideal paddle scale for young Iberian kayakers. The results were as follows: The development of an equation common to the three age categories, U14, U16, and U18, that could explain 75% of the variation in paddle length. Furthermore, also, three predictive equations for each age category represented 67, 33, and 54% of the variation in paddle length for U14, U16 and U18, respectively.

Chapter VIII comprises the general discussion, were the findings of the various studies that compose this Thesis are summarised. Finally, Chapter IX is dedicated to the conclusions. With particular emphasis on the implications and transfer of knowledge, the challenges of future research. The studies in this Doctoral thesis reinforce the need to adjust training and competition to the specificity of the age groups they are designed for. Also claiming the importance of creation of guidelines and global norms with reference indicators for technical skills and properly marking performance benchmarks (maximum and minimum) by age group, that must be complied with, to avoid early specialisation.

The conclusions of this thesis can be summarized as: (a) GPS-Acc devices can considerably reduce the time analysis demanded by the video analysis and facilitate the analysis, with quickness and accuracy, of the performance in terms of boat velocity, stroke rate, and other variables estimated from these – (for example, stroke length and stroke index); (b) the interest of the development of competitive classifications, parallel to the official results, based on biobanding classification; (c) importance of establishing evaluation batteries for young male kayakers, specific for each age group, and the need for creating training programmes that provides young kayakers with the ability to perform the paddle technique with maximum efficiency at high stroke rate; (d) the use of the resulting equations of this Thesis will help to quickly and easily obtain a setup for the length of the paddle.

All agents involved in youth kayaking are encouraged to review, based on the results of the studies of this Thesis, their talent identification and selection process and respective training methodologies.

Keywords: GPS-Acc; Kayaking; RAE; CYE; Maturity; Youth; Paddle Setup.

Resumo

O principal objetivo desta Tese é compreender o desempenho dos jovens kayakistas, nas diferentes fases do seu desenvolvimento maturacional e desportivo, identificando claramente as qualidades explicativas do seu sucesso competitivo, quer estejam relacionadas com aspetos maturacionais, antropométricos ou de equipamento. Procurando oferecer guias de orientação para treinadores e atletas baseados em evidências científicas que auxiliem na tomada de decisão, seja na criação de programas competitivos, treino, avaliação física e de desempenho dos kayakistas, ou na seleção adequada da configuração do equipamento.

A presente Tese está escrita em manuscritos e organizada em nove capítulos. O Capítulo I contém uma introdução geral, enquanto o Capítulo II descreve de forma geral os métodos e procedimentos adotados nos diferentes estudos, incluindo as técnicas estatísticas utilizadas. O Capítulo III centra-se na validação de uma unidade com GPS e um dispositivo acelerómetro desenvolvido para desportos coletivos de campo, mas comumente utilizado por treinadores de canoagem, o que posteriormente facilitará a avaliação do desempenho em competição e treino. Os resultados sugeriram alta concordância entre o GPS-Acelerómetro e os resultados da análise de vídeo, sugerindo que a unidade GPS-Acelerómetro é uma solução valiosa e precisa para avaliar variáveis de tempo e velocidade e, em termos de avaliação da frequência de pagaiada, pode ser ainda mais confiável do que a análise vídeo devido à alta taxa de análise de dados. Esta validação foi fundamental na análise do desempenho da prova simulada no estudo 4 (Capítulo VI). O Capítulo IV inclui um estudo centrado na experiência na modalidade, no estatuto de maturacional e nas suas implicações no desempenho. Os resultados parecem sugerir que os melhores desempenhos são obtidos por kayakistas biologicamente mais maturos, com corpos maiores e mais anos de prática específica, tanto para Sub14 como para Sub16. O Capítulo V compreende um estudo que investiga o estatuto maturacional dos jovens kayakistas e inclui dados sobre os efeitos da Idade Relativa e do Ano Constitutivo. Os dados mostraram que os efeitos do ano constitutivo e o estatuto maturacional parecem influenciar o desempenho nos Sub16. Quanto ao Efeito da Idade Relativa, apesar de não terem sido encontradas diferenças estatisticamente significativas na amostra total ou nas duas categorias avaliadas, uma parte substancial dos dez melhores kayakistas de cada escalão competitivo nasceu entre janeiro e junho e era de maturação precoce. O Capítulo VI contém uma investigação através da qual, analisando diversas variáveis, se procura encontrar uma bateria de avaliação adequada para o escalão competitivo, procurando também compreender a importância da frequência de pagaiada para o desempenho dos jovens kayakistas. Os resultados deste estudo indicam que uma bateria de avaliação específica para o

Sub14 deve incluir a distância do ombro à água, o teste de *shuttle run* e o teste BESS, e para os Sub16, a distância do ombro à água, o teste de *pull-up* e *sit-up*. Além disso, o aumento da frequência de pagaiada está associado a melhores desempenhos nos 200 e 500 m em canoagem juvenil, principalmente na categoria Sub16. O Capítulo VII centra-se na criação de equações preditivas para determinar o dimensionamento ideal para jovens canoístas ibéricos. Os resultados foram os seguintes: O desenvolvimento de uma equação comum às três categorias de idade, Sub14, Sub16 e Sub18, que poderia explicar 75% da variação no comprimento do remo. Além disso, três equações preditivas para cada categoria de idade representaram 67, 33 e 54% da variação no comprimento da raquete para Sub14, Sub16 e Sub18, respectivamente.

O Capítulo VIII compreende a discussão geral, onde são sintetizados os resultados dos diversos estudos que compõem esta Tese. Por fim, o Capítulo IX é dedicado às conclusões. Com particular ênfase nas implicações e transferência de conhecimento, nos desafios da investigação futura. Os estudos desta tese de doutoramento reforçam a necessidade de ajustar o treino e a competição à especificidade das faixas etárias a que se destinam. Afirmando também a importância da criação de diretrizes e normas globais com indicadores de referência para competências técnicas e da marcação adequada de referenciais de desempenho (máximo e mínimo) por faixa etária, que devem ser cumpridos, para evitar a especialização precoce.

As conclusões desta tese podem ser resumidas como: (a) os dispositivos GPS-Acelerómetro podem reduzir consideravelmente o tempo exigido pela análise de vídeo permitindo, com rapidez e precisão, a análise do desempenho em termos de velocidade do barco, frequência de pagaiada, e outras variáveis estimadas a partir destas – (como por exemplo o deslocamento por pagaiada e o índice de ciclo); (b) o interesse de criar classificações competitivas paralelas aos resultados oficiais baseadas na classificação por *biobanding* (c); importância de estabelecer baterias de avaliação para jovens kayakistas do sexo masculino, específicas para a faixa etária, e a necessidade de criar programas de treino que proporcionem aos jovens kayakistas a capacidade de executar a técnica de pagaiada com máxima eficiência a elevadas frequências gestuais; (d) o uso das equações resultantes desta Tese ajudarão a obter de forma rápida e barata uma configuração para o comprimento da pagaia.

Todos os agentes envolvidos na canoagem juvenil são incentivados a rever, com base nos resultados dos estudos desta Tese, o seu processo de identificação e seleção de talentos e respetivas metodologias de treino.

Palavras-chave: GPS-Acc; Kayak; RAE; CYE; Maturação; Jovens; Configuração da Pagaia.

Resumen

El principal objetivo de esta Tesis es comprender mejor el desempeño de los jóvenes kayakistas, en las diferentes etapas de su desarrollo madurativo y deportivo, identificando claramente las cualidades explicativas de su éxito competitivo, ya sean relacionadas con aspectos madurativos, antropométricos o de equipamiento. Buscando ofrecer guías de orientación para entrenadores y deportistas basadas en evidencia científica que ayuden en la toma de decisiones, ya sea en la creación de programas competitivos, entrenamiento, evaluación física y de rendimiento de los kayakistas o en la adecuada selección de la configuración del equipamiento.

Esta tesis está escrita en forma de compendio de publicaciones y está organizada en nueve capítulos. El Capítulo I contiene una introducción general, mientras que el Capítulo II describe los métodos y procedimientos adoptados en los diferentes estudios, incluyendo las técnicas estadísticas utilizadas. El capítulo III se centra en la validación de un equipo con GPS y un dispositivo acelerómetro desarrollado para deportes colectivos de campo, pero de uso habitual por parte de los entrenadores de piragüismo. Los resultados sugieren que la alta concordancia mostrada entre el GPS-Acelerómetro con los resultados del análisis de vídeo sugieren que la unidad GPS-Acelerómetro es una solución válida y precisa para evaluar variables de tiempo y velocidad, y en términos de evaluación de frecuencia de paleo, podría haber sido aún más confiable que el análisis de vídeo debido a la alta tasa de muestreo. Esta validación fue fundamental para analizar el desempeño de la prueba simulada en el estudio 4 (Capítulo VI). El capítulo IV incluye un estudio centrado en la experiencia de piragüismo, el estado de maduración y su implicación en el rendimiento del piragüismo. Los resultados sugieren que los kayakistas más maduros biológicamente, con mayores dimensiones corporales y más años de práctica específica en Sub14 y Sub16 obtienen un mayor rendimiento específico. El capítulo V comprende un estudio que investiga el estado de maduración de los kayakistas jóvenes e incluye datos sobre los efectos de la edad relativa y el año constitutivo. Los datos mostraron que el año constitutivo y el estado de maduración influyeron en el rendimiento de los menores de 16 años. En cuanto al efecto de la edad relativa, aunque no se encontraron diferencias estadísticamente significativas en la muestra total ni en las dos categorías evaluadas, una parte sustancial de los diez mejores kayakistas de cada grupo de edad competitivo nacieron entre enero y junio y se clasificaron como maduros. El capítulo VI contiene una investigación a través de la cual, analizando diversas variables, se intenta encontrar una batería de evaluación adecuada al grupo de edad, buscando también comprender la importancia de la frecuencia de paleo para el desempeño de los jóvenes kayakistas. Los resultados de este estudio indicaron que una batería de evaluación específica para la Sub14 debería incluir la distancia hombro-agua, el *shuttle run test* y el test BESS, y para la Sub16, la distancia hombro-agua, el *pull-up* y *sit-up*. Además, el aumento de la frecuencia de paleo está asociada a mejores rendimientos en los 200 y 500 m en piragüismo juvenil, principalmente en la categoría U16. El capítulo VII se centra en la creación de ecuaciones predictivas para determinar el tamaño de pala ideal para los jóvenes kayakistas ibéricos. Los resultados fueron: El desarrollo de una ecuación común para las tres categorías de edad, Sub14, 16 y 18, que podría explicar el 75% de la variación en la longitud de la pala. Además, tres ecuaciones predictivas para cada categoría de edad explicaron el 67, 33 y 54 % de la variación en la longitud de la pala para U14, 16 y 18, respectivamente.

El Capítulo VIII comprende la discusión general, donde se resumen los resultados de los distintos estudios que componen esta Tesis. Finalmente, el capítulo IX está dedicado a las conclusiones. Con especial énfasis en las implicaciones y transferencia de conocimiento, en los desafíos futuros de la investigación. Los estudios de esta tesis doctoral refuerzan la necesidad de ajustar el entrenamiento y la competición a la especificidad de los grupos de edad a los que están destinados. Afirmando también la importancia de crear directrices y normas globales con puntos de referencia de habilidades técnicas y la adecuada calificación de puntos de referencia de desempeño (máximo y mínimo) por grupo de edad, que deben cumplirse, para evitar una especialización temprana.

Las conclusiones de esta tesis se pueden resumir en: (a) Los dispositivos GPS-Acelerómetro pueden reducir considerablemente el tiempo necesario para el análisis de vídeo permitiendo, de forma rápida y precisa, el análisis del rendimiento en términos de velocidad de la embarcación, frecuencia de remo y otras variables estimadas a partir de estos – (como el desplazamiento por palada y el índice de ciclo); b) el interés de crear rankings competitivos paralelos a los resultados oficiales basados en la clasificación por biobanding; c) importancia de establecer baterías de evaluación de jóvenes kayakistas masculinos, específicas para el grupo de edad, y la necesidad de crear programas de entrenamiento que proporcionen a los jóvenes kayakistas la capacidad de realizar la técnica de paleo con la máxima eficiencia en altas frecuencias gestuales (d) el uso de las ecuaciones resultantes de esta Tesis ayudará a obtener de forma rápida y económica una configuración para la longitud de la pala.

Se recomienda a todos los agentes implicados en el piragüismo juvenil a revisar, a partir de los resultados de los estudios de esta Tesis, su proceso de identificación y selección de talentos y sus respectivas metodologías de entrenamiento.

Palabras Llave: GPS-Acc; Kayak; RAE; CYE; Maduración; Jóvenes; Configuración de Pala.

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List of Abbreviations

%CV — Percentage coefficient of variation
1RM — One-rep-max
1RM — One-rep max
95% CI — 95% Confidence Interval
ANOVA — Analysis of variance
APHV — Age at peak height velocity
ART — Race time
ASR — Average stroke rate
AV — Velocity
BESS — Balance error scoring system
BQ — Birth quarters
CA — Chronological age
CI — Cycle index
CYE — Constituent Year Effect
Diff — Differences
fps — Frames per second
GPS — Global positioning system
GPS/Acc — GPS/Accelerometer
ICC — Intraclass correlation coefficient
ICF — International Canoe Federation
ISAK — International Society for the Advancement of Kinanthropometry
LOA — Limits of the agreement
ns — non-significant
NSCA — National Strength and Conditioning Association
PAH — Predicted adult height
PAH% — Percentage of the predicted adult height
PHV — Peak growth velocity in height
PL:HGD — Paddle length to handgrip distance
r — Pearson's correlation coefficient
R — Model correlation coefficient
RA — Relative age
RAE — Relative age effect

rs — Spearman’s correlation coefficient
RT — Resistance training
S — Significant
SD — Standard deviation
SH — Sitting height
SH:WSD — Sitting height to water-shoulder distance
SL — Stroke length
SR — Stroke rate
SR100 — 100 m splits stroke rate
SRF50 — First 50 m stroke rate
SRL50 — Last 50 m stroke rate
ST — Split times
T100 — 100 m splits time
TF50 — First 50 m split time
TL50 — Last 50 m split time
U14 — Under 14 years of age
U16 — Under 16 years of age
U18 — Under 18 years of age
V — Boat velocity
V100 — 100 m splits velocity
VF50 — First 50 m velocity
VID — Video analysis
VL50 — Last 50 m velocity
Vs — *Versus*
WSD — Water-shoulder distance
η^2 — Eta-squared estimated effect sizes

CHAPTER I: General Introduction

1. General introduction

Sport is perhaps the main form of physical activity during the second decade of life, which includes major changes in body size associated with the adolescent growth spurt. As sports become more competitive and specialised, the identification, detection, and selection of young talents tend to occur at increasingly younger ages.

Naturally, the detection process is influenced throughout growth, being highly individual, resulting in a wide interindividual variability in performance, especially during adolescence (Bunc, 2010). Coaches and researchers have been struggling to adapt the anthropometric profile of athletes to the specific requirements of the sports, aiming to carry them to their maximum performance.

In kayaking, although there are studies that describe attributes, whether anthropometric or physiological, of elite (Michael et al., 2008) and young kayakers (Alacid et al., 2011), few normative data exist in the scientific literature about the optimisation of the equipment set-up according to the human morphology in sprint kayaking (Ong et al., 2005), seeming that an incorrect adjustment of the equipment will affect the comfort of the athlete, his ability to perform the technical movement in perfect conditions, and consequently his performance (Burke & Pruitt, 2003).

The paddles cannot, in any way, be fixed to the boat, and there are no other regulations regarding the shape and size of the paddle and respective blades. The right choice for the length of the paddle (length of the blade; width of the blade and length of the shaft); distance between handgrip; the stature and arm span of the kayaker (Ong et al., 2005). Additionally, having adequate equipment for a child is crucial to a positive learning experience in sports. Many sports agents underestimate the importance of getting the right equipment for young from the very beginning (Hill, 2009).

In sprint kayaking the whole body is used to paddle; however, it is a predominantly upper body sport in which the trunk rotates from a seated base of support and involves concurrent trunk rotation and stabilisation (Mann & Kearney, 1980). Paddlers require significant upper body strength (Akca & Muniroglu, 2008) trunk and core (Fry & Morton, 1991), as well as proper leg movement. Nilsson & Rosdahl (2016) stated that a large gain in speed (16%) is due to leg action, compared with restricted leg action, which may indicate the possibility of emphasising leg action in kayakers to optimise performance.

The measurement of physical fitness in children and youth has long been a topic of interest to physical educators, to exercise and health scientists, and numerous fitness tests have been constructed by physical educators during the last

100 years (Kemper & Mechelen, 1996). Resistance training (RT) in children and adolescents has been reported to have several beneficial effects (Faigenbaum et al., 2009). Additionally, the limited number of investigations conducted with young kayakers did not consider maturational factors in determining paddler profiles and identifying future talent (López-Plaza et al., 2016).

1.1. Study object

Canoe Sprint is one of the most popular competitive canoeing disciplines. The performance criterion is the time required to paddle a designated distance. The average speed with which the paddler can perform the course will determine the best performance (Michael et al., 2008). Kayak competitions are held over distances of 200 m, 500 m, and 1000 m, for all categories of competition, and over distances of 3000 m and 5000 m, depending on the category, in boats that can be crewed by one (K1), two (K2), or four athletes (K4).

The International Canoe Federation (ICF) organises world title-awarding events from the U18 onwards. Usually, in sprint kayaking, the international reference event in the U16 category is the Olympic Hopes Regatta.

Young kayakers are commonly grouped by birth year, in an attempt to provide equal opportunities during competition. Athletes who turn 13 or 14 during the calendar year that refers to that season are in the U14 category. Athletes who turn 15 or 16 during the calendar year referring to that season are in the U16 category. Athletes who turn 17 or 18 during the calendar year referring to that season are in the U18 category.

Kayaking is organised from a selective perspective. And with little capacity to reach the masses, especially if we consider that, between Portugal (≅3,500) and Spain (≅13,500) there are approximately, only 16,000 practitioners of the sport. It is divided into various disciplines and categories of competition. These numbers indicate a great difficulty in retaining athletes at the senior level, which requires particular care in the identification, detection, and selection of talent in kayaking. In addition, it reinforces the need to allow as many young kayakers as possible to enjoy a competitive practise that enables sporting success.

1.2. Biological maturation

From conception to physical maturation in the first 20 years of life, the dominant processes are growth, maturation, and development (Malina et al., 2004). Growth is related to the increase in the size of the body as a whole and its parts. Maturation is related to progress toward biological maturity (maturation is a process and maturity is a state). It involves changes in body size, body proportion, and composition (Baxter-Jones et al., 2005). To correctly understand maturity, it must be recognized that each child has different times and rhythms of maturity. The time is the "when" maturation begins, while the rhythm is the "rate" at which it progresses (Malina et al., 2004). According to Malina et al. (2004), development is related to acquiring qualitative skills (Stratton et al., 2004) and learning proper behaviours expected by society.

Maturation seems to play an important role in motor skill development, strength, and power. Previous research indicates that childhood is ideal and opportunistic for maximising motor skill proficiency (Myer et al., 2011). Moran et al. (2017), in a meta-analysis of maturation-related variation in adolescent boy athletes, showed that resistance training is more effective during and after peak height velocity in boy athletes.

The pubertal jump in growth coincides with a set of events from which I emphasise the peak growth velocity in height (PHV). The time (age) in which the PHV occurs is also considered an indicator of maturity (Malina, 2004; Rowland, 2004; Stratton et al., 2004). The pubertal growth spurt in height in boys begins around age 12, reaches a peak growth rate at around age 14, and ends around age 18 (Figueiredo, 2007). However, it warns that these considerations should be interpreted regarding a large interindividual variability (Philippaerts et al., 2006).

Malina et al. (2004) mention that the range of results reported in studies with the European population indicates that the ages at PHV is between 13.8 and 14.2 years old. Calculating the age of PHV in stature through the formula proposed by Mirwald et al. (2002) has shown to estimate the maturity state within a margin of error of 1.18 years, 95% of the time in boys.

Foreseeing new formulas for determining the mature height without using the skeletal age, Khamis & Roche (1994) used predictor variables where the coefficients for calculating mature height are age-specific. This method was developed with a sample of the Fels longitudinal study, and the authors found an average error in boys, around 2.2 cm height between the predicted and actual height at age 18. This error shows only a slight increase compared to the skeletal age method. The coefficients for the calculation of this method were published again in an erratum by Khamis & Roche (1995).

The maturity offset indicates the temporal distribution proposed by Mirwald et al. (2002), which uses chronological age, body mass, height, sitting height, and leg length. Being the age at PHV is considered the main event of somatic maturation and one of the most used indicators in longitudinal studies, according to Malina et al. (2004), this method proposes to estimate the distance in years, which the subject is of PHV for height, this value can be negative (if the subject has not yet reached the PHV) or positive (if has already exceeded the PHV). For these reasons, all prospective studies in children, both in the context of youth sport and research investigations, must attempt to control for maturity (Baxter-Jones et al., 2005).

There are several questions about the trainability of young athletes, but the answer to these questions remains inconclusive. Concerning strength, it is known that the manifestation of this ability suffers increases during childhood and adolescence, whose variations are attributable to gains in muscle mass and the development of the neuroendocrine and neuromuscular systems (Matos & Winsley, 2007). For the same authors, the prepubertal child and the adolescent can demonstrate significant gains in muscle strength (13-30%) with resistance training. Muscular hypertrophy is limited in prepubertal children but is more often observed from puberty onwards and may reflect changes in the concentrations of growth and sex hormones. Regardless of changes in muscle hypertrophy, neuromuscular adaptations support increase in strength in the young.

Previous canoe studies have focused on analyzing the athletes from a morphological and maturity standpoint (Alacid et al., 2015; Alacid et al., 2011; López-Plaza et al., 2017, 2019), and considering performance (López-Plaza et al., 2016) These studies have evaluated the best paddlers in their categories and reported that the most biologically mature paddlers also showed the best performance.

1.3. Anthropometry

The anthropometric characteristics of athletes are, in most cases, very different, given the specific requirements of each sport, and many of these features are caused by heredity and training, among other factors that can contribute greatly to success. Thus, many researchers have tried to investigate, particularly over the last two or three decades, the physical characteristics of elite athletes to explain athletic performance, linking it with success and failure in sport (Gobbo et al., 2002).

Few studies describe the anthropometric characteristics of young kayakers, and those existing mainly focus on the ages of 13 to 14 years (Aitken & Jenkins, 1998; Alacid et al., 2011; Alacid et al., 2011). Most of the studies that focus part or the entire of his research on kayakers' anthropometry, whether in young or in adults, have been looking at the characteristics commonly associated with success in this sport, i.e., body mass, stature, sitting height, arm span, percentage of body fat, circumference of the upper limb (arm, forearm, relaxed and at maximum contraction), circumference of the chest, biacromial diameter, bi-iliocristal diameter, length of the upper and lower limbs (Aitken & Jenkins, 1998; Ackland et al., 2003; Akca & Muniroglu, 2008; Alacid et al., 2011; Alacid et al., 2011; Gobbo et al., 2002; Someren & Palmer, 2003; Someren & Howatson, 2008).

In their study, Alacid et al. (2011) referred to the characteristics of proportionality in kayakers of the U16 age group, compared to elite paddlers, showing an overall structure with many similarities. The main differences from elite paddlers focused on clearly lower proportions, lower contracted arm circumferences, chest girth, and lower biacromial diameter.

To our knowledge, studies that focus on understanding the relationship between anthropometric characteristics of kayakers and their paddle setup were performed only with adults (Diafas et al., 2012; Ong et al., 2005, 2006). These studies demonstrated that the selection of the length of the paddles, the distance between the grips and the dimensions of the blade are influenced by the stature and dimensions of the upper limbs. The distance between hand grips, for example, can be predicted using chest breadth, stature, and arm span (Ong et al., 2006) reported that only the distance between the handgrips had significant associations with anthropometric parameters, and (Diafas et al., 2012) stated that total arm length, the arm span, and stature were significantly correlated with de paddle length.

1.4. Sport equipment

Sports can be categorised by the energy systems predominantly used. Another way to define the sport is the degree to which the equipment contributes to performance. There are sports where the equipment does not constitute almost any part in determining the result, judo, for instance, and sports in which equipment has a crucial role, like motorsports (Miller, 2005). It does not seem necessary to investigate thoroughly to find evidence of technology in sports. Whether it is a casual runner with the latest model on sneakers, a cyclist of the weekends that boasts a carbon fibre frame, or even a renowned surfer who performs new moves on a board, the technology often has tremendous significance (Hunter, 2011). New materials and equipment designs have long been known to enormously impact sports performance (Miller, 2006).

Olympic flatwater kayaking requires a high level of skill to succeed at the international level, and modifications in technique and equipment are made continuously to improve performance (Kendal & Sanders, 1992). It is possible to observe an increase in the use of technological devices that allow the monitoring of various parameters associated with the performance of athletes. This is particularly noticeable with the help of global positioning system (GPS) devices. This technology has advanced rapidly over the last few tears, and it has become a standard method for assessing the physical demands of training and competition in field sports (Aughey, 2011), like swimming (Le Sage et al., 2011; Siirtola et al., 2011; Thomas et al., 2010).

GPS devices facilitate more objective planning by trying to optimizse future performances (Scott et al., 2016). These devices are replacing the time-consuming and laborious VID methods to quantify the athlete's kinematics in many team sports (Coutts & Duffield, 2010). Moreover, the significant advantage of using these devices is that they enable athletes in real performance situations. The International Canoe Federation (ICF) allows units without real-time information in competition (World Cups, World Championships, and Olympic Games). Since 2017, it has been using GPS/Accelerometer units (GPS-Acc) that contain a 10 Hz GPS (ST Innovation, Geneva, Switzerland).

Since the introduction of flatwater racing as a sport, many technological advances have been introduced in either the kayak's design or the paddle (Michael et al., 2009). However, since an essential regulatory change in the early 2000s related to eliminating the mandatory minimum width of boats, the regulations related to the shape and size of boats remain relatively unchanged. Therefore, a competition K1 must comply with regulations regarding its minimum weight (12 kg) and its maximum length (520 cm). These norms apply transversally to the sprint discipline, regardless of the competition category, which means that young kayakers use the same boat with the same characteristics as adults.

Moreover, in kayaking, the boat is propelled using a double-blade paddle, and kayakers are seated in the boat's cockpit with legs partially extended outright (Michael et al., 2009). According to the ICF competition rules for canoe sprint, published in April 2023, the paddles must not be attached to the boat in any way. There are no other regulations regarding the shape and the size of the paddle and respective blades.

Although the improvements identified in performance cannot be attributed only to changes in equipment design, it was suggested that the change in the shape of the blade (flat to wing blade) had been the technological progress more successful in canoeing, leading to an improvement of the performance time (Robinson et al., 2002). It seems evident that if we consult the time held by the winner in the 1000 m race in the Olympic Games of 1988 (approximately 235 s) and the time held at the Olympic Games of 1992 (approximately 216 s), this trend takes place clearly at the introduction of the wing blade design (Michael et al., 2009). In fact, despite the paddling technique, the introduction of the wing blade design is probably the most important factor in determining the performance of kayaking. Consequently, it will be reasonable to expect that blade characteristics will also play an important role (Sumner et al., 2003). Since the drag force is directly proportional to the front area of the blade, the size of the blade used by the kayaker should correspond to its power generation capacity to be efficient. Suppose the blade size is larger or smaller than the optimum size. In that case, the energy expended by the paddler to keep their race pace is likely to increase (Sprigings et al., 2006), and his ability to perform an efficient technique decreases.

If we focus on the dimensions of the paddle, following Zumerchik (1997), the right choice for the length of the shaft, the distance between the handgrip and the size of the blade, depends on the length, width and mass of the kayak, the stature and arm span of the kayaker. For example, for a given paddle length, the kayaker can alter the mechanical advantage of the propulsion system by simply changing the hand position in the shaft of the paddle (Ong et al., 2006). As a general rule, Rademaker (1977) suggests that the correct distance between handgrips is determined by keeping the paddle shaft above the head with the arms horizontal and the forearms vertically forming a right angle with each other, dividing the paddle into three equal lengths.

Sport imposes a specific morphology for obtaining success in individual sports and requires its own physical characteristics (Norton & Olds, 2001). Still, we must remember that the young athlete is not like the adult athlete, and for that reason, the selection and setup of the equipment, based on specific parameters of the sport and age group, is a critical matter. Having adequate equipment for a child is crucial to a positive learning experience in the sport; It is erroneous to consider the use of adult equipment set-up by young athletes if the equipment will fit as they grow. Many sporting agents underestimate the importance of getting young practitioners the right equipment from the beginning (Hill, 2009).

1.5. Physical fitness

Measurement of physical fitness in children and youth has long been a topic of interest for physical educators, exercise and health scientists, and private organisations dealing with sport, fitness, and health. Physical educators, exercise physiologists, sports physicians, and trainers have constructed numerous fitness tests over the last 100 years (Kemper & Mechelen, 1996).

Physical fitness is the capacity to perform physical activity and refers to a full range of physiological and psychological qualities. Physical activity is any body movement produced by muscle action that increases energy expenditure, whereas physical exercise refers to planned, structured, systematic, and purposeful physical activity (Ortega et al., 2008). For the same author, this characteristic is in part genetically determined, but environmental factors can greatly influence it. Physical exercise is one of the main determinants. Childhood and adolescence are crucial periods, as intense physiological and psychological changes occur at these ages (Ortega et al., 2008).

Physical fitness and physical activity seem very important because maintenance through puberty will probably favour health benefits in later years (Janz et al., 2000). Renfrow et al. (2011) showed that young men who played more sports achieved significantly more healthy fitness zones than those who played fewer sports. Additionally, physical fitness is a good summative measure of the body's ability to perform physical activity and exercise, and it also provides an essential summative indicator of health (Ortega et al., 2008). Physical activity even seems to positively influence cognition (Donnelly et al., 2016).

Furthermore, resistance training (RT) in children and adolescents has attracted an increased interest in improving the components of fitness related to health and performance. The National Strength and Conditioning Association (NSCA) defines RT as a specialised form of conditioning involving the progressive use of a wide range of resistive loads and a variety of training modalities designed to improve health, fitness, and sports performance. Numerous reviews and position papers published by advisory bodies have dismissed previous concerns regarding the safety and efficacy of RT for children and adolescents (Faigenbaum et al., 2009). RT in children and adolescents is reported to have beneficial effects on (1) muscle strength and power; (2) prevention and rehabilitation of injuries; (3) long-term health; (4) cardiovascular fitness; (5) body composition; (6) bone mineral density; (7) blood lipid profiles; (6) self-esteem and (7) mental health (Faigenbaum et al., 2009).

In addition, NSCA reports that strength gains of approximately 30% are typically observed after appropriately designed and supervised short-term RT programmes undertaken by children and adolescents. RT may also benefit sports performance. Increases in adolescents' muscular strength and power levels after participation in RT may improve sporting performance (Faigenbaum et al., 2009). Despite considerable heterogeneity in terms of study design and type of training, there is sufficient evidence to conclude that RT interventions have the potential to improve muscular power in adolescent athletes (Harries et al., 2012).

Recently, Kristiansen et al. (2023), when assessing a group of elite junior, U23, and senior kayakers, demonstrated that in the bench press, the one-rep max (1RM) was the best predictor for a 200 m kayaking performance. Furthermore, the increase in the 1RM in bench press has improved the kayak's performance. Additionally, measuring physical fitness in children and youth has been a topic of interest for physical educators for a long time. Resistance training in youth is reported to have several advantageous effects (Faigenbaum et al., 2009). Gäbler et al. (2021) showed benefits from low-intensity, high-volume strength training regarding the 2000-m performance of young sprint kayakers.

1.6. Sport specialisation

Sports expertise results from complex interactions between biological, psychological, and sociological constraints (Singer & Janelle, 1999), and interest in sport specialization continues to grow (Kliethermes et al., 2021). The perception that early specialisation is the best pathway to attain elite performance originates in talent development studies using experts from multiple fields (eg, chess, musicians, and artists) (Waldron et al., 2020). The ‘ten-year rule’ (Chase & Simon, 1973; Simon & Chase, 1973) or ten thousand hours (Ericsson et al., 1993) stipulates that a commitment of ten years or ten thousand hours to a high level of training is the minimum requirement to reach elite status. Chase & Simon (1973) and Ericsson et al. (1993) also state that skill is not innate, and the interindividual variation in overall performance is due to variations in quantity and quality of training.

It was pointed out by Baker et al. (2003) that experts have accumulated more hours of sport-specific practise since the age of 12 than nonexperts, spending an average of about 13 years and 4,000 hours of concentrated sport-specific practice before reaching the international standard. Ericsson et al. (1993), while supporting the notion that skill is related to the time spent on practise or training, claimed that it was not only the accumulation of hours during ten years of deliberate practice that led to higher performance and that the accumulation of such hours must coincide with the decisive periods of biological and cognitive development. Concluding that the chance of achieving exceptionality in a chosen activity is increased the earlier, the focused training is started by someone.

The age of maximum competitive performance of elite athletes ranges widely between different sports (Allen & Hopkins, 2015). Older athletes are found mainly in sports requiring higher tactical and nautical skills (Longo et al., 2016). In kayaking, the men's K1 1000-m event winners at the Olympic Games of 1996, 2000, 2004, 2008, 2012, and 2016 were, on average, roughly 29 years old. However, in the same event, the three medallists at the Tokyo Olympics are approximately 25 years old. This average drops even further to 22.5 years if we consider only the top two finishers.

Advocates of earlier specialisation argue that sport diversification is not enough for long-term success once it does not allow optimally designed training loads to maximise physiological and psychological adaptations (Baker et al., 2009). However, being conscious of the consequences of promoting early specialisation methods and of research indicating the effectiveness of early diversification underlines that coaches and sports scientists should consider early diversification methods as alternatives (Baker, 2003).

1.7. Outline of the Thesis and objectives

The current thesis is written in manuscripts and is organised into nine chapters. Chapter I contains a general introduction, while Chapter II describes the methods and procedures adopted in the different studies, including the statistical techniques used. Chapters III to VII include the cross-sectional studies (study 1, 2, 3, 4, and 5). The manuscripts composing this thesis have a similar structure with minor adjustments according to the journal's style where the manuscripts are published or in the process of submission. Studies 1 (Fernandes, Alacid, Gomes & Gomes, 2021), 2 (Fernandes, López-Plaza, Correas-Gómez, Gomes, & Alacid, 2021), and 3 (Fernandes, Gomes, & Alacid, 2023) have already published elsewhere, while studies 4 and 5 are being prepared for submission to peer review international journals with impact factor.

Chapter III (Study 1) focuses on validating a unit with GPS and an accelerometer device developed for field team sports but commonly used by coaches in kayaking and canoeing. Chapter IV includes a study that focusses on the kayaking experience, the maturity status, and its implication in kayaking performance. Chapter V comprises a study that investigates the maturity status and includes data from the Relative Age and the Constituent Year Effects. Chapter VI contains an investigation through which, by analysing several variables, an attempt is made to find an adequate evaluation battery for the age group, also trying to understand the importance of the stroke rate for the performance of young kayakers. Chapter VII focusses on creating predictive equations to determine the ideal paddle scaling for young kayakers. Chapter VIII comprises the general discussion, were the findings of the various studiesthat compose this Thesis are summarised.

Finally, Chapter IX is dedicated to the conclusions. With particular emphasis on the implications and transfer of knowledge, the challenges of future research.

Consequently, the main purpose of this Thesis is to better understand the performance of young canoeists, in the different stages of their maturational and sporting development, clearly identifying the explanatory qualities of their competitive success, whether related to maturational, anthropometric or equipment aspects. Trying to offer orientation guides for coaches and athletes based on scientific evidence that help decision making, whether in creating competitive programs, training, kayakers' physical and performance evaluation, or adequate equipment setup selection. Thus, the general objectives of this study are as follows:

a. Assess and validate the use of GPS-Acc technology to quantify kinematic variables of kayaking and canoeing;
b. Identify the importance of biological maturation and the experience in kayaking performance;
c. Analyse maturity status and evaluate the influence of the relative age and the Constituent Year Effects;
d. Determine the variables that better explain the performance of young male kayakers at 200 and 500 m in two different categories, U14 and U16, and identify whether SR is a determinant factor in performance in these categories;
e. To produce predictive equations to determine the ideal kayak paddle scaling for three age categories: U14, U16, and U18.

1.8. References

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CHAPTER II: Methods

2. Methods

2.1. Study design

All studies included in the present Thesis were conducted within projects partially supported by the collaboration protocol signed between the Portuguese Canoe Federation and the Faculty of Sports Sciences and Physical Education of the University of Coimbra and a research contract between the Royal Spanish Canoeing Federation and the University of Almería (ref: 001427), the Research Plan and Transfer of the University of Almería (ref: PPUENTE2022/001), and the Health Research Centre of the University of Almería.

These projects consisted of cross-sectional approaches and was conducted according to the guidelines of the Declaration of Helsinki (Harriss et al., 2017) and approved by the Ethics Committee of the Faculty of Sports Sciences and Physical Education of the University of Coimbra (protocol code CE/FCDEF-UC/00322018).

Data collection was carried out using equipment from two different research units:

(a) The Research Unit for Sport and Physical Activity, Faculty of Sport Sciences and Physical Education, University of Coimbra, Coimbra, Portugal (study 1 to 5);

(b) The Health Research Centre, Faculty of Education Sciences, University of Almería, Almería, Spain (study 2, 3, and 5).

All participants and/or parents/legal guardians volunteered to participate in the studies. In addition, information was provided on the experimental protocol and the objectives of the studies was provided. The inclusion criteria were defined according to the following assumptions:

1. Participants in competitive kayaking in at least three national competitions;
2. Approval in mandatory medical exams;
3. No alcohol consumption;
4. Non-smokers.

And the research team was composed of Canoeing Sport Option students and students of master's courses from the Faculty of Sports Sciences and Physical Education of the University of Coimbra and led by Professors Beatriz Branquinho Gomes (University of Coimbra) and Fernando Alacid (University of Almería) and had the additional collaboration of members of the Ibero-American Network of Researchers in Applied Anthropometry. The basic characteristics of each study are summarised in Table 2.1.

Table 2.1 Design, conditions, sampling, and studied variables involved in each study.

Study	Design	Condition	Sample	Age (years)	Variables
1	Cross-sectional	Field testing	Eight races analized	—	Race time; the average stroke rate; and the velocity
2	Cross-sectional	Field testing	130	14.10 ± 1.06	Quantitative training-related; anthropometry; biological maturation; performance
3	Cross-sectional	Field testing	130	14.10 ± 1.06	Quantitative training-related; birth month and year; anthropometry; biological maturation; performance
4	Cross-sectional	Field testing	24	13.63 ± 1.50	Quantitative training-related; anthropometry; biological maturation; physical fitness; postural stability; equipment characteristics; performance
5	Cross-sectional	Laboratorial testing	149	14.42 ± 1.20	Anthropometry; biological maturation; paddle characteristics

2.2. Procedures

Chronological Age (CA)

CA was established by subtracting the birth date from the date of the first test measurement to the nearest 0.01 year.

Anthropometry

All measurements were taken following the procedures described by the International Society for the Advancement of Kinanthropometry by two certified level 3 anthropometrists and were collected twice, and the mean value was used as the final measure. Body mass (kg) was determined using a SECA 878 (Digital scale, SECA, Germany); stretch stature (cm) and sitting height (cm) with a SECA 206 (Portable stadiometer, SECA, Germany). Arm span (cm) was measured using a metallic tape; the arm length (cm), forearm length (cm), the hand length (cm), the humerus breadth (cm), and the biacromial diameter (cm) were measured using a GPM anthropometer (Siber-Hegner, Switzerland). Relaxed arm girth (cm), the flexed tensed arm girth (cm), and the chest girth (cm) were measured using an anthropometric tape (Rosscraft Tape).

Appendicular Volumetry

The volumes of the upper and lower extremities were assessed in the dominant extremities, following the protocol of Rogowski et al. (2008) and Jones & Pearson (1969), respectively.

Body composition

Skinfold thickness (mm) was measured at six sites (triceps, subscapular, supraspinal, abdominal, front thigh, and medial calf) with a Harpenden skinfold calliper (British Indicators, UK), and the percentage of body fat was estimated from the equation defined by (Slaughter et al., 1988) using triceps and calf skinfolds.

Technical Error of Measurement

All instruments were calibrated before the beginning of each test session to avoid measurement errors. Relative technical error of measurement (Perini & de Oliveira, 2005) for anthropometric was used. All equipment measurements were taken two or three times (if the difference between the two first measures was greater than 1%), and all anthropometric measurements were taken two or three times (if the difference between the two first measures was greater than 5% in skinfolds and 1% in the rest of measures), and the mean or median was used, respectively.

Performance

For performance, in Study 4, the assessments were carried out in calm water, without current or significant wind. Participants were asked to complete a 500-m trial first and then a 200-m one, in a straight line and in the shortest possible time, with a minimum of sixty minutes of rest between trials. Before each test, kayakers were asked to perform their usual pre-race warm-up. For studies 2 and 3, it was considered the official time at the Spanish and Portuguese National Championships that each athlete needed to perform the total distance of the race, 3000 m in the case of the U14 and 5000 m for the U16 kayakers. For that purpose, the results registered by the officials of both competitions were used.

Biological Maturation

Different non-invasive and somatic indicators enable the timing and tempo of the biological processes that occur toward the mature state. To predict the mature stature of young athletes, the procedure proposed by (Khamis & Roche, 1994, 1995) was used.

This method of noninvasive estimation of maturational status, dispenses bone age to calculate the predicted mature height, created by the same author (1993), and provides for the use of current stature, body mass, and mean parental stature. Then we use the multiplication of variables presented by the weighting coefficients associated with the chronological age of the subjects:

Predicted mature stature = intercept + stature × (*coefficient for stature*) + body mass × (*coefficient for body mass*) × mean parental stature × (*coefficient for the mean parental stature*)

The coefficients of the Khamis-Roche method are shown in inches and pounds and require its conversion to a conventional metric system (centimetres and kilograms). The maturational indicator is given by the percentage of predicted adult height already achieved at the time of measurement. This method assumes that an individual who is close to its mature stature is advanced while an individual who is below the predicted mature stature for his age is delayed (Cumming, Standage, Gillison, Dompier, & Malina, 2009):

% Predicted adult height = (height at the moment / predicted mature stature) × 100

To determine the maturity offset it was used the formula proposed by Mirwald et al. (2002). For this purpose, it is necessary to collect the following information: chronological age (CA), stature (s), body weight (w), (wt / h) x 100 (ratio wt/h), length of the lower limb (LL length), and sitting height (sh):

Maturity offset = -9,236 + [0,0002708 × (*LL length* × *sh*)] + [(-0,001663 × (*CA* × *LL length*)] + [(0,007216 × (*CA* × *sh*)] + (0,02292 × *ratio wt/h*)

The result of this equation estimates the distance in years that the subject is of the peak growth velocity for height (PHV), the value can be negative (if not yet reached the PHV) or positive (now surpassed PHV). Biological development was assessed by somatic maturation (Baxter-Jones et al., 2005), the percentage of the predicted adult height (PAH%) defined the maturity status, and the Khamis & Roche (Khamis & Roche, 1994) method was used to estimate the paddlers' predicted adult height (PAH). Mean parental stature was corrected according to Epstein et al. (Epstein et al., 1995). Also, maturity offset was obtained to estimate the distance in years from the peak growth velocity for height (PHV), that the athlete is currently in (Mirwald et al., 2002).

When it was impossible to use the mean parental stature, the Sherar et al. (2005) method was used. This method predicts adult height using the area under cumulative height velocity curves for early, average and late maturing individuals. This method requires a high degree of precision, and the correct collection of stretch saturation, sitting height, requires the use of appropriate measurement protocols. Otherwise, there is the possibility that an individual could be placed in the wrong maturity category.

Equipment Setup

For the equipment set-up, the variables measured were the paddle and blade length, blade width, handgrip distance, the angle between blades, and the distance from the seat to the footrest (Ong et al., 2005). In addition, seat-footrest distance (cm) and vertical water-shoulder distance (cm) were also included.

The paddle length (cm) was measured using metallic tape. Blade length (cm), blade width (cm), and handgrip distance (cm) were measured using a sliding calliper GPM anthropometer (Siber-Hegner, Switzerland). Angle between blades was measured using a device with a protractor (Smart Protractor version 1.5.8). Finally, the vertical water-shoulder distance was measured using an apparatus specially developed and a laser beam (Bosch, GLM 40 Professional). All variables were collected twice and the mean value was used as the final measure.

Physical Fitness

The physical fitness was assessed by performing the overhead medicine ball throw (Gabbett & Georgieff, 2007). Because of the importance of trunk rotation in the paddle technique (Kendal & Sanders, 1992; Michael et al., 2009), an adaptation of this test for lateral medicine ball throw with the kayakers taking a seated position similar to the kayak paddling stance. The sit-and-reach test was used to determine hamstring flexibility (Lopez-Miñarro et al., 2013). The multistage 20 m shuttle-run test (Léger & Lambert, 1982) was used to test kayakers' will and drive. The pull-up, push-up and sit-up tests were assessed following the Fitnessgram test battery (The Cooper Institute for Aerobics Research, 1999), and the handgrip strength test following the Eurofit test battery methodology (Council of Europe, 1988) using a dynamometer (Hand Dynamometer - Lafayette model J00105, USA).

Before all physical tests, the investigators provided clear instructions for each procedure. General warm-up consisted of eight minutes of multidirectional running activity and five minutes of general dynamic stretching of the upper and lower extremities delivered and supervised by a certified canoe sprint level 2 coach. During the evaluations, the same sequence of tests was applied. When assessing physical fitness, only the best of three attempts in each trial was considered for analysis, giving at least three minutes of rest between trials, except for the 20 m multistage shuttle run test, which was performed once. The warm-up involved five minutes of acquaintance with the materials and procedures before each test, excluding the shuttle run test.

Postural Stability

The balance error scoring system (BESS) measures static balance and postural stability. It combines three stances (narrow double leg stance, single-leg stance, and tandem stance) and uses two footing surfaces (firm surface/floor or medium density foam) for the test (Iverson & Koehle, 2013). The athlete must stand barefoot,up on the ground and each trial is 20 seconds. The number of errors (deviations) from the proper stance should be counted only after the individual has assumed the proper testing position, and for a single test positioning 10 is the maximum number of errors.

Global Positioning System and Accelerometery

Boat displacement, velocity, and acceleration were obtained using a wireless unit with a 15 Hz GPS and a 3D IMU. This unit contains 12 channel receivers that track up to 12 satellites at any time. It is combined with a triaxial accelerometer with a sampling rate of 100 Hz (GPSPORT, Canberra, Australia) and is fixed on the stern of the deck of the kayak/canoe, synchronising GPS and IMU data. Data were extracted to spreadsheets with Team AMS R1 2016.7.

Statistical Analyses

Different statistical analyses were performed according to the specific objective of each study (Table 2.2.). Consequently, different software and instruments were used: IBM SPSS software versions 24.0 and 27.0 (Statistical Package for Social Sciences, SPSS, Chicago, USA), Microsoft® Office Excel 365. Statistical significance was set at $p < 0.05$.

Table 2.2. Statistical analyses for each study.

Analyses	Study				
	1	2	3	4	5
Descriptive statistics		•	•	•	•
Kolmogorov-Smirnov test		•	•		•
Shapiro-Wilk test	•	•		•	
Intraclass correlation coefficient	•				
Bland-Altman plot	•				
Pearson’s correlation		•			
Spearman’s	•	•		•	•
One-way analysis of variance	•	•	•		
One-sample t-test	•				
Effect size	•		•		
Coefficient of variation					
Kruskal–Wallis	•			•	•
Chi-square			•		
Stepwise multiple linear regression					•

2.3. References

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CHAPTER III: Study 1

3. Validation of a global positioning system with accelerometer for canoe/kayak sprint kinematic analysis.

Reference: Fernandes, R.A., Alacid, F., Gomes, A.B., & Gomes, B.B. (2021). Validation of a global positioning system with accelerometer for canoe/kayak sprint kinematic analysis. Sports Biomechanics, 1–12. https://doi.org/10.1080/14763141.2021.2005128

3.1. Abstract

Sport is perhaps the main form of physical activity during the second decade This study aimed to validate the use of a Global Positioning System with an accelerometer (GPS-Acc) unit to quantify canoeing kinematic variables. Eight canoe and kayak (200 and 500 m) sprint races were analysed. All the races were recorded sideways by a digital camera that followed the kayak or canoe bow and simultaneously using a GPS-Acc wireless unit recorded the data concerning boat position, velocity, and acceleration. In 200 m races, 50 m splits were established over the entire race distance. In 500 m races, 100 m splits were used, excepting the race start and end, where the splits were divided into two sections of 50 m. The data of the GPS-Acc unit were analysed using a self-developed routine. The agreement between the video and the GPS-Acc analysis was measured regarding all the variables by a Bland-Altman analysis. No differences were found between both methodologies, except for time and velocity at the first 50 m, suggesting thus an agreement between the analysis methods. Therefore, the GPS-Acc unit is valid for measuring quickly and accurately kinematic variables, mainly boat velocity and stroke rate. However, video analyses may be necessary when a more detailed analysis of the paddling technique is of interest.

Keywords: Canoe sprint; validation; kinematic; analysis.

3.2. Introduction

Canoe Sprint is one of the most popular competitive canoeing discipline. Kayak and canoe competitions are held over distances of 200 m, 500 m, and 1000 m in boats that can be crewed by one, two, or four athletes. Most athlete's training evaluation is conducted in laboratory environment (Bishop et al., 2003; Fleming et al., 2012; Fohanno et al., 2010; Gomes et al., 2012; Harrison et al., 2019; Kerr et al., 2008;; Limonta et al., 2010; Sprigings et al., 2006; Sumner et al., 2003; Someren & Oliver, 2002) and few studies in controlled training situations on the water (Aitken & Neal, 1992; Bonaiuto et al., 2020; Gomes et al., 2015, 2020; Mann & Kearney, 1980; McDonnell et al., 2012). These assessments are often used to measure performance or evaluate training effects, but there is a disadvantage in laboratory tests of ergometers because they do not fully replicate the sport's specific performance (Larsson, 2003).

In canoeing, video analysis (VID) is a standard tool for kinematic analysis (Alacid et al., 2005; Vaquero-Cristóbal et al., 2013), since the paddler and kayak/canoe are recorded sideways from a motorboat or vehicle following the race/training situation. Using the buoys on the course as distance references (Sperlich & Baker, 2002), variables such as boat velocity (V), stroke rate (SR), stroke length (SL), and split times (ST) could be calculated. In addition, considering that the SR usually establishes training intensity in canoeing, the coaches often quantified it by using stopwatches. Different studies carried out on canoeing suggested that the SR is the variable that best correlates with performance (Brown et al., 2011; Gomes et al., 2015; Gomes et al., 2020; McDonnell et al., 2013). Nowadays, it is possible to measure the SR by using a sensor attached to the paddle shaft and synchronised with a sportwatch or smartphone. However, it increases the paddle weight, which could interfere with the technique, aside from the fact that its use is not allowed in competition.

Global positioning system (GPS) technology has rapidly advanced over the last few tears. It has become a standard method for assessing the physical demands of training and competition in field based sports (Aughey, 2011). For example, studies conducted in swimming accurately enabled the stroke count detection for all four-stroke styles using the GPS technology (Le Sage et al., 2011; Siirtola et al., 2011; Thomas et al., 2010). GPS devices facilitate a more objective planning, by attempting to optimise future performances (Scott et al., 2016). These devices have been replacing the time-consuming and laborious VID methods to quantify the athlete's kinematics in many team sports (Coutts & Duffield, 2010). Moreover, the significant advantage of using these devices is that they enable to monitor athletes in real performance situations.

The International Canoe Federation allows units without real-time information in competition (World Cups, World Championships, and Olympic Games). Since 2017, it has been using GPS/Accelerometer (GPS-Acc) units containing a 10 Hz GPS (ST Innovation, Geneva, Switzerland). (Goreham et al., 2020) used these data in their study to investigate the pacing strategies of elite athletes and analysed the differences between medallists and non-medallists. Furthermore, some studies used GPS-Acc technology to analyse kayaking performance in a training environment (Bifaretti et al., 2016), and even to analyse the SR, comparing data from the GPS-Acc unit with the video analysis (VID) (McDonnell et al., 2012). (Bifaretti et al., 2016) suggested that a high refresh frequency of the GPS module (10 Hz) could evaluate the intra-cyclic velocity variation, which may not be possible with a standard 1 Hz device, since it depends mainly on the SR values. On the other hand, McDonnell et al. (2012), when testing sprint kayakers performance, compared the SR values calculated based on GPS-Acc data (1Hz GPS and 125 Hz Acc) to the video information (60 Hz; a camera mounted on the deck of the kayak) and found that GPS-Acc was not a valid measure for the SR. Therefore, they suggested the use of VID (McDonnell et al., 2012). Probably this result was due to the low GPS sampling rate used by these authors.

Although GPS-Acc units' frame rates have increased over the past years, their data have not been validated in comparison with the VID. Therefore, investigation in this field of research is still scarce. Thus, this study aimed to assess and validate the use of GPS-Acc technology to quantify canoeing kinematic variables. The agreement between VID and GPS data for boat velocity was hypothesised as well as the possibility of obtaining accurate SR measurements with Acc data, in contrast to the ones performed using the VID.

3.3. Materials and methods

Participants and data collection

Data were collected in 2018 during the Portuguese Canoe Sprint National Championships and the International Canoe Federation Canoe Sprint World Championships. Both events were held at the High-Performance Center of Montemor-o-Velho, Portugal.

Eight races were considered for analysis in the present study, corresponding to the K1 200 m junior men (Heat and A Final) and women (Heat, Semi-final, and A

Final), the K4 500 m senior men (Heat), the K2 500 m junior women (A Final) and C1 500 m senior men (Heat). With their agreement, all athletes were filmed during the race, and their boats had a GPS-Acc unit. This study received approval from the ethics committee (CE / FCDEF-UC / 00322018).

Following the instructions of the official international canoeing competitions, the race started with the athletes aligned on the respective lanes with an automatic start system (Tegysport S.A.S; Macerata, Italy). At the start of the race, all boats had their bow on the starting bucket. And the starting frame considered was the one in which the bucket started to drop. The athletes' reaction time was not assessed.

In 200 m races, 50 m splits were established over the entire race distance. Meanwhile, 100 m splits were used in 500 m races, except for the first and last sections, which were divided into two sections of 50 m. The 0-50 m and 450-500 m splits were analysed because the error tends to be greater in these smaller splits than in the larger ones (Alacid et al., 2005). The variables assessed were the race time (ART), the average stroke rate (ASR), and the velocity (AV). For the first 50 m split, time (TF50), stroke rate (SRF50), and velocity (VF50) were assessed. For the last 50 m split, time (TL50), stroke rate (SRL50), and velocity (VL50) were assessed; and for each intermediate 100 m splits, time (T100), stroke rate (SR100), and velocity (V100) were assessed.

The video recording was carried out by means of a digital camera with a recording mode at 30 frames per second (fps), mounted on a camera stabilizer (Xiaomi Mijia Gimbal Model SJYT01FM, Beijing, China). The entire race was recorded sideways accompanying the athlete, always following the kayak or canoe bow when passing the marking buoys (that were placed every 10 m on each lane of the course) and adjusting whenever necessary to facilitate the data analysis. The resulting recordings were analysed by using the software *Kinovea - 0.8.15*. The data obtained from the digitalisation were registered in a Microsoft© Excel spreadsheet (Microsoft Corporation, USA). In order to calculate velocity, the frame, in which the boat's bow was aligned with the two buoys that marked each split, was determined (Figure 3.1.).

Figure 3.1. Example of the video analysis frame to consider bow alignment with the two buoys that mark a split.

Subsequently, the distance analysed was divided by the number of frames elapsed in the split by 30 fps (frames per second), obtaining results in m.s^{-1}. In order to determine the SR, the methodology described by (Alacid et al., 2005) was used. Thus, the complete stroke cycles were counted for each split, considering the frame in which the paddle blade on the recording side came into contact with the water. These frames were always equal or superior to those used to determine the velocity, that is, the first blade entry was performed after completing the split. All athletes started their race with the left paddle submerged, and the race was filmed from the right side. An additional stroke was added for the first 50 m.

After getting these data, the number of stroke cycles obtained in the elapsed frames was divided by 30 fps, and the results were expressed in cycles.s^{-1} (Alacid et al., 2005). Since the stroke rate is commonly used in canoeing and displayed as the number of strokes per minute (spm) (McDonnell et al., 2013), the previous number was multiplied by 60 seconds. Finally, two experienced observers that are experts in canoeing (one of them has a published study using the aforementioned methodology) analysed the video data.

Simultaneously, the boat displacement, velocity, and acceleration were obtained by using a wireless unit with a 15 Hz GPS and a 3D IMU. This unit contains 12 channel receivers that track up to 12 satellites at any time. It is combined with a triaxial accelerometer with a sampling rate of 100 Hz (GPSPORT, Canberra, Australia) and it is fixed on the stern of the deck of the kayak/canoe, synchronizing GPS and IMU data. The data were extracted to spreadsheets with the software Team AMS R1 2016.7. Then, they were exported to Matlab® R2019b (The MathWorks Inc., Natick, MA) and analysed using a routine especially developed for this application. In the routine, the investigator had to identify the start of the race by taking into consideration the first index in which the velocity changed from 0 m.s^{-1} to a higher value (representing the start of the race). Afterwards, taking into account the data position (x and y coordinates), the routine itself identified the end of the race, evaluating the total distance (200 or 500 m) and the different splits in analysis. At the same time, by considering the defined splits, the velocity was computed for the total race distance and splits (50 and 100 m). Furthermore, the SR was added (total race and splits) by considering kayak longitudinal acceleration. A fourth-order low-pass Butterworth filter with a cut-off frequency of 10 Hz was used to smooth the acceleration data (Winter, 2009) and to identify each stroke by a single peak. The displacement splits data (50 or 100 m) enabled to determine the acceleration data cuts and identify the total strokes per distance split. The variables analysed were the average velocity (race and splits), the average stroke rate (race and splits), and the total race time.

3.4. Statistical analysis

The normality and homogeneity of the variance hypotheses were verified using the Shapiro-Wilk and Levene's tests. Spearman's correlation coefficients (*rs*) were calculated to examine the correlation between the outcomes. These coefficients were considered as a very high correlation when the value is between 0.9 and 1, a high correlation when between 0.7 and 0.9, a moderate correlation when between 0.5 and 0.7, a low correlation when between 0.3 and 0.5, and a negligible correlation when between 0 and 0.3 (Mukaka, 2012).

The difference between the methods concerning the mean values was analysed using the one-sample t-test. In addition, a one-way analysis of variance (ANOVA) was used to examine the differences between the race time resulting from the VID, the race time resulting from the GPS-ACC, and the race official time.

The level of significance was set at $p < 0.05$. Cohen's d was used to measure the effect size of the observed differences and was considered small when the value was between 0.2 and 0.5, moderate when between 0.5 and 0.8, and large when the effect was > 0.8 (Cohen, 1988).

The agreement between methods was explored concerning all the variables, systematic bias and random error calculated by Bland-Altman analysis (Bland & Altman, 1986, 1990), including upper and lower limits of the agreement (LOA) through the typical error $\left(\frac{SD}{\sqrt{2}}\right)$ as suggested by (Hopkins, 2000). Consequently, the 95% LOA was calculated by $\left(\pm\left(1.96s \cdot \sqrt{2}\right) \cdot \left(\sqrt{2}\right)s\right)$. The coefficient of variation

(CV%) was calculated as $\left(\frac{s}{mean} \cdot 100\right)$, LOA 95% confidence intervals were calculated in Microsoft® Office Excel 365. Furthermore, the heteroscedasticity was examined using linear regression, inserting the difference from the mean values between methods as the dependent variable, and the average values [(value for VID + value for GPS-Acc)/2] as the independent variable ($p < 0.05$). The statistical analyses were performed using SPSS Statistics 24.0 (SPSS Inc., Chicago, IL).

3.5. Results

The kinematic variable's results are summarised regarding both methods, the VID analysis and GPS-Acc unit, in Table 3.2. They were normally distributed, and the homogeneity of variance was not violated. The intraclass correlation coefficient (ICC) and the percentage coefficient of variation (%CV) are shown in Table 3.1. The ICC was excellent (Koo & Li, 2016) and ranged between 0.9 and 1.0 concerning the variables under study.

Table 3.1. Intraclass correlation coefficient (ICC), percentage coefficient of variation (%CV), and 95% Confidence Interval (95% CI) between observations.

Variables	*n*	ICC	%CV	95% CI
ART (s)	8	1.00	0.1 – 1.7	1.00 – 1.00
ASR (spm)	8	0.99	0.4 – 2.0	0.995 – 1.00
AV ($m.s^{-1}$)	8	1.00	0.0 – 1.6	1.00 – 1.00
TF50 (s)	8	1.00	0.0 – 0.4	0.999 – 1.00
SRF50 (spm)	8	0.996	0.0 – 4.8	0.981 – 0.999
VF50 ($m.s^{-1}$)	8	1.00	0.0 – 0.8	0.999 – 1.00
TL50 (s)	8	1.00	0.0 – 0.7	0.998 – 1.00
SRL50 (spm)	8	0.999	0.0 – 4.4	0.993 – 1.00
VL50 ($m.s^{-1}$)	8	1.00	0.0 – 0.8	0.998 – 1.00
T100 (s)	25	0.999	0.0 – 1.1	0.994 – 0.999
SR100 (spm)	25	1.00	0.0 – 1.2	0.999 – 1.00
V100 ($m.s^{-1}$)	25	1.00	0.0 – 4.4	0.999 – 1.00

n: Number of observations, ART: Average race time; ASR: Average stroke rate; AV: Average velocity; TF50: Time at first 50 metres; SRF50: Stroke rate at first 50 metres; VF50: Velocity at first 50 metres; TL50: Time at last 50 metres; SRL50: Stroke rate at last 50 metres; VL50: Velocity at last 50 metres; T100: Time at 100 metres splits; SR100: Stroke rate at 100 metres splits; V100: Velocity at 100 metres splits.

No statistically significant differences were found between the methods, except for TF50 ($p < 0.01$) and VF50 ($p < 0.01$). The effect size ranged from small to moderate concerning the variables that did not show statistically significant differences and it was considered as large for TF50 ($d = 1.4$) and VF50 ($d = 1.3$). Spearman's correlation was ranked between high and very high (Table 3.3.). Moreover, no statistically significant differences between the obtained race times were found as it was determined by one-way ANOVA [(F(2,12)= 0.000, $p = 1.00$]. The heteroscedasticity test does not show variance in data dispersion.

Table 3.2. Mean values (±SD) and 95% confidence intervals for the means of kinematic variables in VID and GPS-ACC analysis.

	n	**VID**		**GPS-ACC**		***p***	***d***
		Mean ± SD	**95% CI**	**Mean ± SD**	**95% CI**		
ART (s)	8	68.39 ± 33.66	45.06 – 91.71	68.12 ± 33.89	44.64 – 91.61	0.08	0.7
ASR (spm)	8	126.63 ± 29.87	105.93 – 147.32	126.00 ± 29.37	105.64 – 146.36	0.38	0.3
AV (m.s^{-1})	8	4.58 ± 0.59	4.17 – 4.99	4.61 ± 0.60	4.19 – 5.02	0.06	0.8
TF50 (s)	8	11.77 ± 1.25	10.90 – 12.64	11.41 ± 1.20	10.50 – 12.24	*<0.01	1.4
SRF50 (spm)	8	140.00 ± 25.07	122.63 – 157.37	141.63 ± 26.58	123.21 – 160.04	0.13	0.6
VF50 (m.s^{-1})	8	4.29 ± 0.47	3.97 – 4.61	4.43 ± 0.47	4.10 – 4.75	*<0.01	1.3
TL50 (s)	8	11.75 ± 1.72	10.56 – 12.93	11.81 ± 1.87	10.52 – 13.11	0.40	0.3
SRL50 (spm)	8	115.50 ± 33.61	92.21 – 138.79	114.38 ± 32.89	91.58 – 137.17	0.08	0.7
VL50 (m.s^{-1})	8	4.33 ± 0.60	3.92 – 4.74	4.32 ± 0.63	3.88 – 4.75	0.57	0.2
T100 (s)	25	21.88 ± 3.19	19.68 – 24.09	21.80 ± 3.19	19.59 – 24.01	0.16	0.3
SR100 (spm)	25	116.24 ± 32.90	93.44 – 139.04	115.72 ± 32.28	93.35 – 138.08	0.14	0.3
V100 (m.s^{-1})	25	4.67 ± 0.71	4.18 – 5.16	4.69 ± 0.71	4.19 – 5.18	0.57	0.3

n: Number of observations, ART: Average race time; ASR: Average stroke rate; AV: Average velocity; TF50: Time at first 50 meters; SRF50: Stroke rate at first 50 meters; VF50: Velocity at first 50 metres; TL50: Time at last 50 metres; SRL50: Stroke rate at last 50 metres; VL50: Velocity at last 50 metres; T100: Time at 100 metres splits; SR100: Stroke rate at 100 metres splits; V100: Velocity at 100 metres splits; VID: video analysis; GPS-ACC: GPS/Accelerometer data; SD: standard deviation; 95% CI: 95% confidence intervals; *d:* Cohen effect size.
**alpha* < 0.05

The level of agreement between the VID and GPS-ACC analysis for kinematic variables is shown in Table 3. The data suggest the agreement between the methods, except for TF50 and VF50, with a more significant discrepancy of the limits of agreement around the mean being observed with a large amplitude between the upper and lower limits, and with a more considerable bias in these variables (TF50= 0.4 ± 0.2 s, VF50= -0.1 ± 0.1 m.s^{-1}) than in the analogous variables for the last 50 m (TL50= -0.1 ± 0.2 s, VL50= 0.0 ± 0.1 m.s^{-1}) and in the 100 m splits (T100= 0.1 ± 0.3 s, V100= 0.0 ± 0.1 m.s^{-1}).

Table 3.3. Spearman's correlation and Bland-Altman analysis of the agreement between VID (video analysis) versus GPS-ACC (GPS/Accelerometer).

	n	Bias	SD	LOA	r_s	*p*
VID versus GPS-ACC						
ART (s)	8	0.3	0.4	[-0.8, 1.3]	0.97*	<0.000
ASR (spm)	8	0.6	1.9	[-4.7, 6.0]	0.99*	<0.000
AV (m.s^{-1})	8	0.0	0.0	[-0.1, 0.1]	0.95*	<0.000
TF50 (s)	8	0.4	0.2	[-0.3, 1.0]	0.86*	<0.006
SRF50 (spm)	8	-1.6	2.7	[-9.2, 5.9]	0.89*	<0.003
VF50 (m.s^{-1})	8	-0.1	0.1	[-0.4, 0.2]	0.86*	<0.006
TL50 (s)	8	-0.1	0.2	[-0.7, 0.5]	0.97*	<0.000
SRL50 (spm)	8	1.1	1.6	[-3.2, 5.4]	0.99*	<0.000
VL50 (m.s^{-1})	8	0.0	0.1	[-0.2, 0.2]	0.97*	<0.000
T100 (s)	25	0.1	0.3	[-0.7, 0.9]	0.98*	<0.000
SR100 (spm)	25	0.5	1.7	[-4.3, 5.3]	0.99*	<0.000
V100 (m.s^{-1})	25	0.0	0.1	[-0.2, 0.2]	0.98*	<0.000

n: Number of observations, ART: Average race time; ASR: Average stroke rate; AV: Average velocity; TF50: Time at first 50 m; SRF50: Stroke rate at first 50 m; VF50: Velocity at first 50 m; TL50: Time at last 50 m; SRL50: Stroke rate at last 50 m; VL50: Velocity at last 50 m; T100: Time at 100 m splits; SR100: Stroke rate at 100 m splits; V100: Velocity at 100 m splits; SD: standard deviation; LOA: Limits of agreement; r_s: Spearman's correlation.
*$p < 0.05$

In Figure 3.2., it is possible to observe the level of agreement in Bland-Altman scatterplots concerning the average velocity and stroke rate for the total race, first and last 50 m and 100 m intermediate splits.

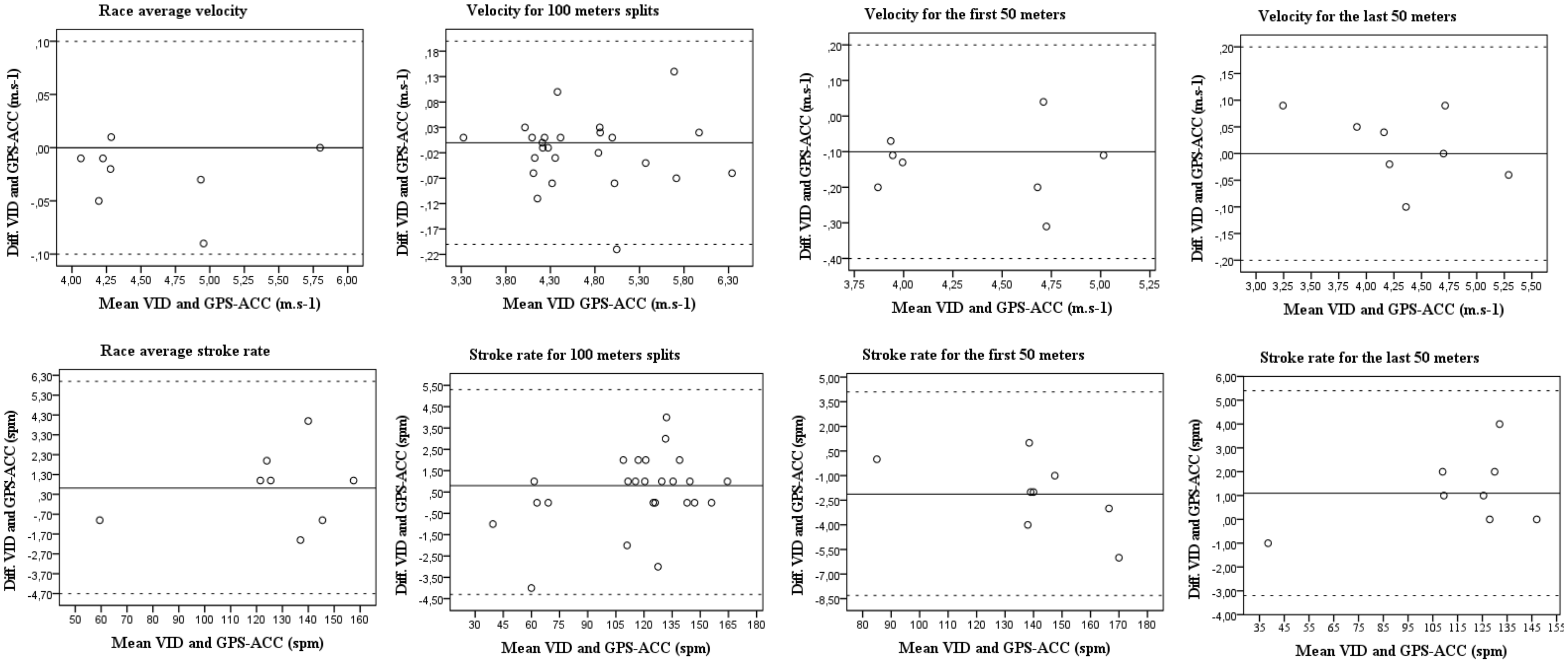

Figure 3.2. Differences (Diff.) between VID and GPS-Acc for the kinematic variables – velocity and stroke rate, for total race-distance, first and last 50 m, and splits of 100 m.

3.6. Discussion and implications

This study evaluated the validity of GPS-Acc technology usage (GPS 15 Hz, Acc 100 Hz) as opposed to VID to quantify kinematic variables (performance time, velocity, and stroke rate) in canoeing, by assessing kayaks and canoes of one, two, and four paddlers over different sprint distances (200 and 500 m). As far as we know, this work was the first to attempt a comparison analysis with both types of vessels in a real competition situation.

This paper's main finding was the agreement between the stroke rate analysis methods concerning all the distance splits (total race, 50 m start, intermediate 100 m splits, and 50 m finish). There was also agreement regarding the velocity analysis, except for the start of the race (first 50 m). This analysis took into consideration a broad spectrum of average velocities (3.20 and 6.65 $m.s^{-1}$) and stroke rates (31 and 168 spm) performed in a canoe sprint competition since it has assessed boats of one, two, and four paddlers on a canoe or kayak.

The results show that the GPS-Acc unit accurately recorded the stroke rate, at a considerable range of the SR, throughout the entire racecourse, regardless of whether it was the race start, intermediate splits, or the last metres before crossing the finish line. A significant increase in the SR from 0 to a high value defines the race start. This increment depends on the type of boat, the number of athletes, and the level of performance. With regard to the intermediate splits, the SR will depend on the race distance and the strategy adopted, besides the athlete's performance level. In the last metres of the race, in terms of the SR, what stands out is that the shortest the race distance, the more frequent is the chance of the athlete performing a stronger paddle stroke to launch the boat, trying to reach the finish line more quickly. Thus, Acc data have been demonstrated to obtain the SR accurately for kayak and canoe, regardless of the race stage, and irrespective of whether increasing, maintaining, decreasing, or even including the launch stroke at the end of the race. In a study assessing velocity and stroke count data using a GPS-Acc unit, compared to data obtained from a concurrently recorded digital video of the performance, this unit proved to be a valid tool for stroke count quantification in breaststrokes and butterfly stroke (Beanland et al., 2014). In contrast, (McDonnell et al., 2012), when studying canoeing, stated that the stroke rate should be evaluated with the VID for an accurate research in elite kayaker's performance since the SR data obtained by the GPS-Acc unit proved not to be valid for measuring stroke rate. These authors suggested that it should be used only when immediate feedback is valuable. On the contrary, our study suggests that the data from the GPS-Acc unit can be accurate and valid for evaluating stroke rate. The different conclusions between studies in canoeing may be due to the use of varying sampling rates, both in VID and in GPS-Acc. McDonnell et al. (2012) do not explain how, by means of the GPS-Acc unit, the data from the SR were extracted, therefore not allowing the comparison between methodologies. The compared analysis of the SR, between the two methods under analysis, can probably suggest that the accuracy considerably depends on the sampling rate of the technology used to collect the data, which, in this case, is higher for the Acc unit (100 Hz), compared to the video recording (30 Hz).

The evaluation of the stroke rate in canoeing is critical because this is the variable with the highest correlation with average kayak velocity and performance (Brown et al., 2011; Kendal & Sanders, 1992; McDonnell et al., 2013). Croft and Ribeiro (2013) have also suggested that intensity zones could be defined only by stroke rate in training. Although the observed differences are not statistically significant, the analysis may be affected at the end of the race. For example, some athletes can "launch" the boat by performing paddle strokes with durations different from the ones they normally do during the race and, in some cases, even stopping paddling before the end of the race. This situation requires extra care by the investigator/coach when interpreting the data.

The velocity variables in the analysis showed no differences between the two methods, which confirms that the GPS can accurately determine the times and velocity. The results showed a nonsignificant tendency for overestimation of the GPS-Acc unit regarding the average velocity of the total race. In opposition to our findings, previous studies in kayaking (Janssen & Sachlikidis, 2010) and human locomotion either on foot (Townshend et al., 2008) or by bicycle (Witte & Wilson, 2004) have reported that GPS data tend to underestimate velocity. In 2004, (Witte & Wilson, 2004) suggested that the limitation of GPS technology is that the satellite position may influence the accuracy of velocity measures. However, technological advances have increased the number of satellites used to triangulate and calculate position, and the sample rate increase, thus improving data accuracy. Recent studies (Bataller-Cervero et al., 2019; Beato et al., 2018), using different methodologies in field-based activities, have demonstrated the use of GPS as an accurate alternative to recording straight line velocity.

The VID may have had greater accuracy to assess velocity in the present study because its sampling rate was 30 Hz, which was higher than the one of the GPS unit (15 Hz). In terms of velocity, one aspect that can influence the compared analysis is the paddler's reaction time to the starting signal. For the race start analysis, by means of the VID, the movement of the starting bucket was taken into consideration. For the GPS analysis, it was considered the index in which the velocity changed from 0 to a positive value since it was not possible to determine in these data when the starting bucket was activated. In a study with elite sprinters, (Tønnessen et al., 2013) stated that reaction abilities affect sprint performance since reaction time on stationary starts may have a noticeable influence on velocity data and, consequently, on performance. Thus, the significant differences observed between the methods used for time and velocity at the first 50 m may be because the VID took into account the official start, which was defined by the movement of the starting bucket. The GPS-Acc data were based on the boat's changing of velocity from 0 to a higher value, thus removing the impact of the athlete's reaction time.

One of the advantages of using GPS technology is that it enables a quick post-event analysis of the kinematic variables under study (McDonnell et al., 2012). Then, based on the estimates resulting from that analysis, other variables of interest include the distance per stroke and the stroke index. This quickness can be crucial in competition, enabling the race strategy analysis immediately after heat, semifinal, and final, taking into consideration that canoe sprint race regulations do not allow athletes to use devices that show them real-time kinematic data. Furthermore, GPS technology has the advantage of enabling to choose from different distance splits according to the investigators/coaches' interests. However, although they enable quick feedback, the data obtained by the GPS-Acc analysis do not enable other kinematic analyses of the paddling technique that the VID does, such as linear and angular kinematics of the different phases of the paddling stroke.

A limitation of the study is that it reports to data collected by a GPS-Acc in canoe sprint races performed in the northern hemisphere, specifically in the European territory (Portugal), which can influence the number of satellites used for triangulation beyond the impact of the time of the day on the GPS data, as reported by (Janssen & Sachlikidis, 2010). Future investigations should use units from other brands to verify the validity of their use in canoe sprint and other territories. In addition, this study uses different VID and GPS-Acc sampling rates to analyse the variables, considering that the available GPS technology is limited to around 15 Hz. Another limitation is the possible video error sources due to the parallax effect. Finally, given the data analysis, the fact that different indexes were considered regarding the start of the race, in the VID it was the official start and in the GPS-Acc unit it was the boats' movement start, could also have limited the comparison. The agreement observed concerning the variables related to the SR is the main finding of this research. The SR is one of the most used variables to define training intensity and is the variable most correlated with performance. These results suggest the GPS-Acc unit as a valuable and accurate solution to assess time and velocity variables. In terms of the SR assessment, it could have been even more reliable than the VID due to the high rate of data analysis. GPS-Acc devices can considerably reduce the time analysis demanded by the VID and facilitate the analysis of the training sessions, competition velocity, SR, and other variables estimated from these. The device with a higher sampling rate could be more accurate (VID – 30 Hz and GPS – 15 Hz), as verified in the present study concerning time and velocity variables. However, the GPS-Acc, even so, showed a high agreement with the VID. Thus, considering the needs of researchers and coaches, the use of both methods could be of interest. The GPS-Acc unit, because it enables to measure the variables analysed in this study with quickness and accuracy, and the VID whenever a more detailed analysis of the paddling technique is required.

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CHAPTER IV: Study 2

4. The importance of biological maturation and years of practice in kayaking performance

Reference: *Fernandes, R.A., López-Plaza, D., Correas-Gómez, L., Gomes, B.B., & Alacid, F. (2021). The Importance of Biological Maturation and Years of Practice in Kayaking Performance. International Journal of Environmental Research and Public Health, 18(16), 8322. https://doi.org/10.3390/ijerph18168322*

4.1. Abstract

Previous Canoe Sprint studies have evaluated the best paddlers of their categories. This investigation aimed to identify the importance of biological maturation and athlete's experience in kayaking performance and observe possible differences regarding anthropometry, years of practice, and performance. Eighty under 14 years of age (U14) and fifty under 16 years of age (U16) kayakers aged 13.40 ± 0.54 and 15.25 ± 0.61 years, were evaluated. Kayakers were assessed for anthropometry (body mass (kg); stretch stature (cm) and sitting height (cm)), performance (time at 3000 m for U14 and 5000 m for U16 kayakers), and somatic maturation (predicted adult height (PAH) and maturity offset). In U14 kayakers, years of practice, sitting height, and maturity offset showed significant differences ($p < 0.05$) between Top10 and Middle, and Middle and Bottom10 performance times. Significantly higher ($p < 0.05$) sitting height were identified between Top10 and Middle U16 kayakers. Significant differences ($p < 0.05$) were observed for maturity offset and PAH% between Top10 and Middle compared to Bottom10 group. In conclusion, this research showed differences in the maturity status of young U14 and U16 kayakers, identifying that the more biologically mature individuals, and with more years of specific practice achieved better performances.

Keywords: Kayaking; years of practice; maturity; performance; anthropometry.

4.2. Introduction

The International Canoe Federation recognizes various disciplines, with Canoe Sprint being, probably, the most popular (Borges et al., 2013). In all competitive categories from under 14 and all levels of competition, national or international, the official events are 200 m, 500 m, and 1000 m that are performed in venues duly marked by buoys. Also, in sprint canoeing, long-distance competitions of 3000 m for under 14 kayakers and 5000 m for under 16 paddlers and above are held on a predefined circuit that paddlers typically must repeat clockwise. Generally, these competitions have substantial participation of young kayakers, and in many countries, such as in Portugal and Spain, a pre-qualification competition must be organized to ultimately select the paddlers that will participate in the National Championship. Therefore, during these age-group competitions and considering the age, participants with different levels of competition experience can be found.

Chronological age, which is calculated as a single time point away from the date of birth, has traditionally been used in sports to group age-grade participants, identify talented performers, and set limits for exercise prescription (Lloyd et al., 2017). Despite this, literature has demonstrated that individuals of the same chronological age can differ concerning biological maturity (Baxter-Jones et al., 2005).

Talent identification programs are designed to identify young athletes with the potential to succeed in senior elite categories (Vaeyens et al., 2009). The literature shows that traditional talent identification and development models exclude many talented children from supporting programs (Malina et al., 2019). Most of these children seem to beat early stages of their biological maturation compared to other athletes of the same chronological age or category (late maturers) (Vaeyens et al., 2008). Moreover, evidence shows that early specialization is not the only way to achieve expertise (Coutinho et al., 2016). The age of peak competitive performance of elite athletes ranges widely between different sports (Allen & Hopkins, 2015). Older athletes are found mainly in sports requiring higher tactical skills and nautical sports (Longo et al., 2016). In kayaking, the winners of the men's K1 1000 m event at the Olympic Games of 1996, 2000, 2004, 2008, 2012, and 2016 were, on average, roughly 29 years old. Thus, talent identification and development models must be sensitive to differentiate between an athlete's adolescent performance level and potential for progression (Vaeyens et al., 2008). Previous models showed that talent is usually assessed exclusively by exceptional performances (Abbott & Collins, 2002), not considering other factors such as maturity status or sport-specific experience. Currently, it seems clear that the performance profiles are multidimensional, and several characteristics should be considered for this purpose (Sieghartsleitner et al., 2019). Any talent identification process must acknowledge and account for maturity-related variation in performance (Lloyd et al., 2017). Avoiding less mature children to drop out of a sport because of a lack of perceived competence or lack of success (Delorme & Raspaud, 2009).

From conception to physical maturation in the first twenty years of life, the dominant processes are growth, maturation, and development (Malina et al., 2004). Growth is related to the increase in the size of the body as a whole and its parts. Maturation is a process, and maturity is a state. Maturation is related to progress towards biological maturity. It involves changes in body size, body proportion, and composition (Baxter-Jones et al., 2005), and these changes may affect performance. Maturation seems to play a significant role in motor skill development, strength, and power. Previous research indicates that childhood is ideal and opportunistic to maximize motor skill proficiency (Myer et al., 2011). Moran et al. (2017), in a meta-analysis of maturation-related variation in adolescent boy athletes, showed that resistance training is more effective during and after peak height velocity in boy athletes. In addition, the interest in this topic in the context of youth sports is evident. Several studies about bio-banding in football (bio-banding is the process of grouping practitioners based on attributes associated with growth and maturation and not chronological age) have been conducted (Cumming et al., 2017, 2018; Malina et al., 2019; Rogol et al., 2018). Previous canoeing studies have focused on analyzing the athletes from a morphological and a maturity standpoint (Alacid et al., 2011; Alacid et al., 2015; López-Plaza et al., 2017, 2019), considering performance (López-Plaza et al., 2016). These studies have evaluated the best paddlers of their categories and reported that the most biologically mature paddlers also showed the best performances.

This approach does not allow access to the entire population of under 14 and 16 kayakers, making impossible the design of a more comprehensive and complete evaluation battery. Furthermore, considering the evidence that an individual's biological maturation influences the detection process, it is vital to analyze more heterogeneous groups of kayakers to design these batteries with the sensitivity to evaluate and value the athletic potential of kayakers and not just the immediate performance.

It is also essential to understand the influence that years of specific practice may have on the performance of athletes in younger categories. It has been identified that intense training extended for a minimum of ten years leads to expert performance (Ericsson et al., 1993). Ward et al. (2007) showed that, although they start playing soccer at a similar age, the elite players began training in a team environment earlier than sub-elite players. This team practice contributes to the difference in performance. However, Olympic world-class athletes started training, competing, and participating in international competitions later than peers performing at a national level and also have competed in other sports not only their main sport (Vaeyens et al., 2009). Another claim for late specialization is that before focusing on a single sport, engagement in multiple sports has benefits in core motor skills and coordination (Fransen et al., 2012). Côté et al. (2007) have stated that the senior international level is attainable with less than five years of practice in the sport. Macnamara et al. (2016) reported no difference in starting age between higher and lesser skilled athletes and also stated that, on average, deliberate practice accounted for 18% of the variance in sports performance. The remaining 82% of the variance may, hypothetically, be explained by other factors. Côté et al. (2009) have concluded that sports sampling does not harm future expert performance.

Thus, it was hypothesized that biological maturation and years of kayaking practice might influence performance times. Therefore, this investigation aimed to identify the importance of biological maturation and athlete's experience in kayaking performance and observe possible differences regarding anthropometry, years of practice, and performance times.

4.3. Materials and methods

Participants

This study involved 130 young Spanish and Portuguese male kayakers, 80 under 14 years of age (U14) and 50 under 16 years of age (U16), aged 13.40 ± 0.54 and 15.24 ± 0.61 years, respectively. Which represents 55,2% of the U14 and 34,5% of the U16 kayakers who participated in the championships. Data collection took place at the Spanish and Portuguese National Championships, with about a month of difference. In both competitions, good weather with no wind and racecourse conditions with flatwater and no current were verified. These competitions were organized by the Royal Spanish Canoeing Federation and the Portuguese Canoe Federation.

Athletes were assessed throughout the day, considering their competition schedule. All participants with less than one year of practice were excluded from the assessment, and all had passed the mandatory medical exams necessary to participate in national competitions in both countries. The Ethical Committee approved the experimental procedures, and before the beginning of the study, written parental or guardian informed consent was obtained.

Anthropometry

All measurements were taken following the procedures described by the International Society for the Advancement of Kinanthropometry by two certified level 3 anthropometrists. Body mass (kg) was determined using a SECA 878 (Digital scale, SECA, Germany); stretch stature (cm) and sitting height (cm) with a SECA 206 (Portable stadiometer, SECA, Germany). Instruments were calibrated before the beginning of each testing session to avoid measurement errors. Relative technical error of measurement (Perini & de Oliveira, 2005) was 0.11% for stretch stature, 0.11% for sitting height, and 0.03% for body mass.

Performance

For performance, it was considered the official time that each athlete needed to perform the total distance of the race, 3000 m in the case of the U14 and 5000 m for the U16 kayakers. For that purpose, the results registered by the officials of both competitions were used. All participants were then distributed into groups depending on the years of practice at the time of the assessment: <3 years (Bottom-Exp), ≥3 to <5 years (Mid-Exp), and ≥5 years (Top-Exp); and depending on the performance time: Top10, Middle, and Bottom10.

Maturity status

Different non-invasive indicators enable understanding the tempo and timing of the biological processes that occur toward the mature state. Somatic maturation was used to evaluate the biological development (Baxter-Jones et al., 2005), maturity status was defined by the percentage of the predicted adult height (PAH%) and by the athlete predicted adult height (PAH). The procedure used to estimate adult height was proposed by Khamis & Roche, (1994). This method uses the current height, body mass, and mean parental height, which was corrected according to Epstein et al., (1995) equation. This method assumes that an individual who is close to its mature height is "advanced" while an individual who is below the predicted adult height for his age is "delayed" (Cumming et al., 2009).

All participants were distributed into groups depending on their maturity status (Cumming et al., 2017) at the time of the assessment: <88% (Bottom%PAH), ≥88% to <92% (Middle%PAH), and ≥92% (Top%PAH) for the U14 category, and <95% (Bottom%PAH), ≥95% to <97% (Middle%PAH), and ≥97% (Top%PAH) for the U16 kayakers. Also, maturity offset (Mirwald et al., 2002) was used. This method uses chronological age, height, body weight, lower limb length, and sitting height to estimates the distance in years that the subject is from the age at peak height velocity (APHV). The value can be negative if APHV is not yet reached or positive if APHV is surpassed.

4.4. Statistical analysis

The hypotheses of normality were verified using the Kolmogorov–Smirnov and Shapiro-Wilk test while the homogeneity of variance was analysed using the Levene's test. The comparisons of group mean for maturation, years of practice, and performance time was performed using a one-way analysis of variance (ANOVA) test when statistical tests revealed no violations of the assumptions of normality and homogeneity. If one-way ANOVA analysis demonstrated significant differences, post hoc Bonferroni tests were conducted to allocate the differences between groups. Kruskal–Wallis test was used when normality supposition of data was not verified, and post hoc tests with Bonferroni corrections were applied. The level of significance was set as $p < 0.05$. Pearson's correlation coefficient (r) was used to determine the relationships between performance, biological maturation, years of practice, and anthropometry. Spearman's correlation coefficients (r_s) were calculated when the assumptions of normality were violated. They were considered a very high correlation when 0.9–1, a high correlation when 0.7–0.9, a moderate correlation when 0.5–0.7, a low correlation when 0.3–0.5, and a negligible correlation when 0–0.3 (Mukaka, 2012). Statistical analysis was performed using SPSS Statistics 27.0 (SPSS Inc., Chicago, IL).

4.5. Results

The chronologial age years of practice, anthropometry, maturity, and performance parameters in U14 and U16 paddlers are presented in Table 4.1.

Table 4.1. Mean values (± SD) of chronological age (CA), years of practice, anthropometry, maturity, and performance parameters in U14 and U16 paddlers.

	Mean (± SD)	
	U14 (n=80)	U16 (n=50)
CA (years)	13.40 ± 0.54	15.24 ± 0.61
Years of Practice (years)	3.29 ± 1.46	4.12 ± 2.01
Anthropometry		
Stretch Stature (cm)	163.75 ± 9.22	172.52 ± 5.59
Sitting Height (cm)	85.49 ± 4.98	90.75 ± 3.50
Body Mass (kg)	55.06 ± 10.73	63.68 ± 6.78
Maturity		
Maturity offset (years)	-0.06 ± 0.78	1.61 ± 0.65
APHV (years)	13.46 ± 0.64	13.62 ± 0.52
PAH (cm)	182.07 ± 6.61	179.77 ± 5.44
PAH (%)	89.90 ± 3.01	96.06 ± 1.73
Performance		
3000 m time (s)	870.32 ± 116.14	–
5000 m time (s)	–	1450.95 ± 90.52
Average velocity ($m.s^{-1}$)	3.50 ± 0.44	3.45 ± 0.21

CA: chronological age; APHV: age at peak height velocity; PAH: predicted adult height.

Kayakers grouped by bands based on the percentage of predicted adult height, by years of practice, and by performance

Table 4.2. summarises the data related to chronological age, years of practice, anthropometry, maturity, and performance parameters by groups based on PAH% (Bottom%PAH, Mid%PAH, and Top%PAH), years of practice (Bottom-Exp, Mid-Exp, and Top-Exp) and performance (Top10, Middle and Bottom10) in the U14 category.

Chronological age presented significant differences between the groups based on PAH% ($p < 0.05$) for the three defined maturity groups, with the kayakers from the Top%PAH group being older than the rest (Mid%PAH and Bottom%PAH group). Kayakers from the Top%PAH group were substantially heavier than the rest, particularly the Bottom%PAH group. However, there are no significant differences for the performance variables under study between the three maturity groups in this category, although the best performances are obtained by the Top%PAH (857.47 ± 141.10 s).

When grouped by performance, no significant differences for the chronological age were identified. However, it was possible to verified that Top10 kayakers were significantly more experienced than Middle and Bottom10 (4.40 ± 1.26, 3.25 ± 1.48 and 2.60 ± 0.96 years, respectively, $p < 0.05$). Significant differences ($p < 0.05$) were also found between stretch stature (169.55 ± 3.93 cm) and APHV (161.08 ± 8.56 cm) between Top10 and Bottom10 groups, and PAH% revealed significant differences between Top10 (92.33 ± 1.16 %, $p < 0.05$) and Middle-performance (89.52 ± 3.00 %, $p < 0.05$) times groups.

As for U16 kayakers (Table 4.3.), when compared by groups based on the PAH%, kayakers from the Top%PAH group (15.75 ± 0.37 years, $p < 0.05$) revealed significantly older than kayakers from Mid%PAH (15.29 ± 0.52 years, $p < 0.05$) and Bottom%PAH group (12.82 ± 0.48 years, $p < 0.05$). When grouped by years of practice, chronological age has shown significant differences ($p < 0.05$) between the Bottom-Exp (1.73 ± 0.48 years) and Mid-Exp (3.41 ± 0.49 years) groups and between the Bottom-Exp (1.73 ± 0.48 years) and Top-Exp groups (6.42 ± 1.10 years). The performance showed significantly best performances ($p < 0.05$) between Top10 and Bottom10 performance times. At the same time, the comparison by years of practice showed that the kayakers form Top-Exp group were significantly faster ($p < 0.05$) than the rest of the groups.

In the comparison between groups of performance, kayakers who obtained the Bottom10 performance times revealed significantly lower chronological age ($p < 0.05$) compared with the remaining groups (Top10 and Middle).

U16 kayakers had significantly ($p < 0.05$) larger body dimensions for sitting height, between Top10 and Middle performances. Also, regarding maturity offset and PAH%, Top10 and Middle groups, when compared to Bottom10 performances, were significantly ($p < 0.05$) more mature.

Relationship between performance and chronological age, years of practice, anthropometry, and maturity

Table 4.4. shows an overview of the relationships between performance time and chronological age, years of practice, anthropometry, maturity, and average velocity for the U14 and U16 groups. For both age groups, negative and significant relationships were found in the years of practice, sitting height, maturity offset, and average velocity. A negligible and moderate correlation was identified in the U14

and U16 groups, respectively, in the analysis of the years of practice ($p < 0.05$, $p < 0.01$, respectively). Interestingly, chronological age has shown a significant and negative association with the performance time for the group of U16 kayakers. It is noteworthy that a negative correlation with time of performance in competition means better results for kayakers in the respective variables under analysis, with the exception of APHV.

Table 4.2. Mean (± SD) for chronological age (CA), years of practice, anthropometry, maturity, and performance parameters for bands based on the percentage of predicted adult height (Bottom%PAH, Mid%PAH, and Top%PAH), grouped by years of practice (Bottom-Exp, Mid-Exp, and Top-Exp) and grouped considering performance (Top10, Middle and Bottom10) for under 14 kayakers.

	Under 14 (n=80) - Mean (± SD)								
	Groups by bands based on the PAH%			Groups by years of practice			Groups by performance		
	Bottom%PAH (n=19)	Mid%PAH (n=37)	Top%PAH (n=24)	Bottom-Exp (n=29)	Mid-Exp (n=36)	Top-Exp (n=15)	Bottom10 (n=10)	Middle (n=60)	Top10 (n=10)
CA (years)	12.82 ± 0.48	13.44 ± 0.57*	13.78 ± 0.31†§	13.38 ± 0.52	13.40 ± 0.56	13.43 ± 0.52	13.64 ± 0.62	13.33 ± 0.51	13.52 ± 0.53
Years of Practice (years)	3.39 ± 1.63	3.16 ± 1.39	3.41 ± 1.47	1.82 ± 0.48	3.48 ± 0.52*	5.66 ± 0.61†§	2.60 ± 0.96	3.25 ± 1.48	4.40 ± 1.26†§
Anthropometry									
Stretch Stature (cm)	152.42 ± 8.24	165.31 ± 5.59*	170.32 ± 5.90†	162.79 ± 9.92	165.67 ± 8.57	161.00 ± 8.91	161.08 ± 8.56	163.23 ± 9.60	169.55 ± 3.93†
Sitting Height (cm)	80.21 ± 4.63	85.98 ± 3.75*	88.90 ± 3.32†§	84.83 ± 5.18	86.65 ± 4.85	83.96 ± 4.52	82.85 ± 4.19	85.29 ± 5.08	89.33 ± 2.51†§
Body Mass (kg)	46.87 ± 12.40	54.42 ± 7.72*	62.52 ± 8.19†§	53.40 ± 11.98	57.33 ± 9.92	52.82 ± 9.55	54.62 ± 12.50	54.16 ± 10.98	60.92 ± 4.41
Maturity									
Maturity offset (years)	-1.02 ± 0.56	-0.00 ± 0.52*	0.61 ± 0.39†§	-0.16 ± 0.82	0.10 ± 0.75	-0.24 ± 0.72	-0.25 ± 0.63	-0.12 ± 0.81	0.51 ± 0.41†§
APHV (years)	13.85 ± 0.75	13.44 ± 0.57*	13.17 ± 0.45†	13.54 ± 0.65	13.29 ± 0.59	13.67 ± 0.63	13.89 ± 0.56	13.46 ± 0.63	13.01 ± 0.41†
PAH (cm)	178.35 ± 8.02	183.18 ± 5.46*	183.30 ± 6.17†	181.40 ± 6.60	183.58 ± 6.77	179.7 ± 5.66	179.50 ± 6.55	182.23 ± 6.75	183.68 ± 6.5
PAH (%)	85.44 ± 1.77	90.24 ± 1.07*	92.91 ± 0.83†§	89.67 ± 2.91	90.23 ± 3.06	89.55 ± 3.01	89.73 ± 3.38	89.52 ± 3.00	92.33 ± 1.16§
Performance									
3000 m time (s)	889.10 ± 99.35	869.01 ± 107.90	857.47 ± 141.10	902.59 ± 111.00	865.66 ± 126.66	819.11 ± 79.53	1093.03 ± 44.13	859.37 ± 70.69*	713.29 ± 19.34†§
Average velocity ($m.s^{-1}$)	3.41 ± 0.37	3.50 ± 0.41	3.58 ± 0.53	3.36 ± 0.38	3.53 ± 0.47	3.69 ± 0.37	2.75 ± 0.11	3.51 ± 0.28*	4.21 ± 0.11†§

CA: chronological age; APHV: age at peak height velocity; PAH: predicted adult height.

*Significant difference ($p < 0.05$) between Bottom%PAH and Mid%PAH bands, between Bottom-Exp, and Mid-Exp, and between Bottom10 and Middle

†Significant difference ($p < 0.05$) between Bottom%PAH and Top%PAH, between Bottom-Exp and Top-Exp, and between Bottom10 and Top10

§Significant difference ($p < 0.05$) between Mid%PAH and Top%PAH bands, between Mid-Exp, and Top-Exp and between Middle and Top10

Table 4.3. Mean (± SD) for chronological age (CA), years of practice, anthropometry, maturity, and performance parameters for bands based on the percentage of predicted adult height (Bottom%PAH, Mid%PAH, and Top%PAH), grouped by years of practice (Bottom-Exp, Mid-Exp, and Top-Exp) and grouped considering performance (Top10, Middle and Bottom10) for under 16 kayakers.

	Under 16 (n=50) - Mean (± SD)								
	Groups by bands based on the PAH%			Groups by years of practice			Groups by performance		
	Bottom%PAH (n=16)	Mid%PAH (n=18)	Top%PAH (n=16)	Bottom-Exp (n=13)	Mid-Exp (n=18)	Top-Exp (n=19)	Bottom10 (n=10)	Middle (n=30)	Top10 (n=10)
CA (years)	14.66 ± 0.32	15.29 ± 0.52*	15.75 ± 0.37†§	14.75 ± 0.39	15.43 ± 0.60*	15.38 ± 0.56†	14.62 ± 0.29	15.31 ± 0.58*	15.65 ± 0.41†
Years of Practice (years)	2.96 ± 1.70	4.02 ± 1.95	5.37 ± 1.95†	1.73 ± 0.48	3.41 ± 0.49*	6.42 ± 1.10†§	2.35 ± 0.88	4.41 ± 2.23*	5.00 ± 1.47†
Anthropometry									
Stretch Stature (cm)	171.60 ± 5.96	170.94 ± 4.40	175.21 ± 5.74	171.12 ± 6.19	172.24 ± 5.28	173.74 ± 5.48	170.04 ± 4.71	172.73 ± 5.56	174.38 ± 6.12
Sitting Height (cm)	89.57 ± 3.70	89.93 ± 2.66	92.84 ± 3.39†§	88.84 ± 3.21	90.29 ± 2.85	92.48 ± 3.59†	88.51 ± 2.90	90.98 ± 3.17	92.30 ± 4.14†
Body Mass (kg)	61.71 ± 7.85	62.52 ± 4.56	66.96 ± 6.91	61.23 ± 7.06	64.28 ± 7.10	64.78 ± 6.18	58.35 ± 5.44	64.79 ± 6.32*	65.68 ± 7.20†
Maturity									
Maturity offset (years)	1.13 ± 0.54	1.52 ± 0.44	2.19 ± 0.50†§	1.08 ± 0.50	1.66 ± 0.60*	1.93 ± 0.58†	0.93 ± 0.45	1.69 ± 0.52*	2.05 ± 0.69†
APHV (years)	13.53 ± 0.56	13.76 ± 0.44	13.56 ± 0.55	13.67 ± 0.50	13.77 ± 0.44	13.45 ± 0.57	13.68 ± 0.43	13.61 ± 0.54	13.59 ± 0.58
PAH (cm)	182.48 ± 5.86	178.09 ± 4.86	178.94 ± 4.85	180.89 ± 6.68	178.64 ± 4.46	180.06 ± 5.45	180.12 ± 4.96	176.65 ± 5.89	179.75 ± 4.93
PAH (%)	90.03 ± 0.91	96.24 ± 0.67*	97.90 ± 0.67†§	94.61 ± 1.54	96.41 ± 1.69*	96.73 ± 1.34†	94.41 ± 1.67	96.15 ± 1.51*	97.45 ± 1.02†
Performance									
5000 m time (s)	1489.59 ± 83.36	1450.55 ± 101.23	1412.77 ± 71.07†	1532.66 ± 64.16	1439.57 ± 89.53*	1405.83 ± 69.90†	1583.36 ± 30.49	1445.01 ± 53.29*	1336.39 ± 18.60†§
Average velocity (m.s^{-1})	3.36 ± 0.18	3.46 ± 0.23	3.54 ± 0.17†	3.26 ± 0.13	3.48 ± 0.20*	3.56 ± 0.17†	3.16 ± 0.06	3.46 ± 0.12*	3.74 ± 0.05†§

CA: chronological age; APHV: age at peak height velocity; PAH: predicted adult height.

*Significant difference ($p < 0.05$) between Bottom%PAH and Mid%PAH bands, between Bottom-Exp, and Mid-Exp, and between Bottom10 and Middle

†Significant difference ($p < 0.05$) between Bottom%PAH and Top%PAH, between Bottom-Exp and Top-Exp, and between Bottom10 and Top10

§Significant difference ($p < 0.05$) between Mid%PAH and Top%PAH bands, between Mid-Exp, and Top-Exp and between Middle and Top10

Table 4.4. Correlations between chronological age, years of practice, anthropometry, maturity parameters with performance in U14 and U16 kayakers groups (*r* and r_s).

	Under 14 (n=80)	Under 16 (n=50)
	3000 m	5000 m
Chronological Age	0.030	– 0.426**$^{+}$
Years of Practice	– 0.240*$^{\wedge}$	– 0.535**$^{\wedge}$
Anthropometry		
Stretch Stature	– 0.278*$^{\wedge}$	– 0.223
Sitting Height	– 0.314**$^{\wedge}$	– 0.375**$^{+}$
Body Mass	– 0.141	– 0.168
Maturity		
Maturity offset	– 0.261*$^{\wedge}$	– 0.493**$^{+}$
APHV	0.305**$^{+}$	0.112
PAH	– 0.215	– 0.020
PAH (%)	– 0.202	– 0.393**$^{\wedge}$
Performance		
Average velocity	– 0.988**$^{+}$	– 0.998**$^{+}$

APHV: age ate peak height velocity; PAH: predicted adult height.

*Significant differences ($p < 0.05$)

**Significant differences ($p < 0.01$)

$^{+}$ Pearson's and $^{\wedge}$ Spearman's correlations

4.6. Discussion

The objective of this study was to analyze the importance of biological maturation and the athlete's experience in specific kayaking performance. As hypothesized, biological maturation and years of practice have some influence on performance times.

Building an athlete to reach his maximum possible performance is a long process with many factors that may influence and determine a kayaker's overall performance. Some of the most common factors affecting performance are technique, experience, maturity status, physiological and anthropometric characteristics, equipment, personality, health, tactics and strategies, nutrition, and environmental conditions (Cox, 1992).

The main findings of this work were that for performance groups of U14 kayakers, regarding years of specific practice, the Top10 athletes showed significantly more years of practice than Middle and Bottom10. Despite no significant differences for chronological age was found between these same groups, suggesting that there were athletes who start their specific practice at very young ages compared to their peers in the same category. Concerning performance groups and biological maturation, Top10 U14 showed significant differences in maturity offset between the rest of the kayakers (Middle and Bottom10), and significant differences in PAH% only with the Middle kayakers group. Mirwald et al. (2002) showed that performance changes are particularly evident just before and during the onset peak height velocity. López-Plaza et al. (2016) stated significant differences between maturity groups and performance, suggesting that maturity status is a predictor of race performance and may reveal the importance of maturity status at similar chronological age.

In contrast, for U16 group, the Top10 kayakers only revealed differences for years of practice and chronological age with the Bottom10 athletes. In U16 kayakers, both maturity offset and PAH% showed significant differences between Top10 and the Bottom10 groups. These differences may be causality in both situations, as the Top10 kayakers are just over one year older than the Bottom10 athletes.

According to Ackland et al. (2003), basic anthropometric variables have been considered relevant when identifying the elite Olympic paddlers. These same characteristics also prove to be important in identifying elite young paddlers (Alacid et al., 2011; López-Plaza et al., 2017), and additionally, Hamano et al., (2015) have reported height as a determinant factor in kayaking. However, the results of the U14 group in stretch stature, sitting height, and body mass were below those reported in previous studies with young kayakers (López-Plaza et al., 2016), probably because previous studies (López-Plaza et al., 2016, 2019) have assessed the best athletes in their categories, instead of different levels.

Similarly, prior research has reported taller and heavier kayakers (López-Plaza et al., 2016, 2019) than the U16 paddlers of the present study. In addition, they were advanced in terms of maturity offset (1.97 ± 0.89, 1.61 ± 0.65 years, respectively). However, focusing on the Top10 kayakers at 5000 m, these were advanced in maturity offset. The results for stretch stature, sitting height, and body mass were similar to those reported in 2019 by López-Plaza et al. (2019).

Biological maturation is related to physical performance during adolescence and is more pronounced when comparing boys with a wide range of maturity statuses. Since generally, athletes of different competitive levels are characterized by average or advanced maturity status (Beunen & Malina, 2007), maturation is discriminatory in sports where the best performances are dependent on the physical level (Vaeyens et al., 2008). López-Plaza et al., (2016) have reported that in kayaking and canoeing, the more biologically mature paddlers obtained the best paddling times. The differences in growth and maturation seem to contribute to the selection process in individual sports such as tennis and table tennis (Myburgh et al., 2016; Coelho-e-Silva et al., 2022) and team sports such as basketball (Guimarães et al., 2019).

In the present study, significant differences between 3000 m performances were observed in U14 groups only when the kayakers were compared by groups of performance. Despite, there were no significant differences for chronological age. It was observed that the best kayaking times were obtained by more mature and with more years of specific practice kayakers, which can contribute to a higher level of technical execution, and it may result from a likely increase in strength. When evaluated by groups based on PAH%, despite significant differences regarding maturity offset and PAH%, the differences were not observed in the years of practice. Conversely, when evaluated by groups of experience, differences were observed in years of practice, but not in terms of maturity offset and PAH%. Revealing that to verified significant differences in performance, a combination of years of practice and indicators of somatic maturation is necessary for the U14 group.

Previous studies have shown that larger body size was associated with better performances (Fry & Morton, 1991; Someren & Howatson, 2008), as well as chronological age and maturity status have been identified as the best predictors of paddling times (López-Plaza et al., 2016). This is particularly noticeable in U16 kayakers where, in any of the three forms of grouping (groups by bands based on the PAH%, by years of practice and by performance), there were significant differences in chronological age, years of practice, sitting height, maturity offset, and PAH% with apparently evident repercussions on performance times. Although, in both categories, U14 and U16, when compared by performance groups, the best performances were also associated with advanced maturational profiles, maturity offset and PAH%.

The data obtained in the present research also suggests that more years of specific practice resulted in better performances. Alves & Silva, (2009) showed that the Portuguese men's kayaking team (19.60 ± 1.90 years), in preparation for the Beijing Olympic Games, had 7.3 ± 2.1 years of practice, training 11.6 ± 0.7 sessions per week and a mean of 3.2 ± 0.4 hours of daily training. Allen & Hopkins, (2015) stated that differences in the attributes required for success in different sporting events probably contribute to elite athletes' wide range of peak-performance ages.

Regarding the relation with performance, the chronological age (r= -0.426) and the PAH% (r_s= -0.426) only correlated significantly (p< 0.01) for the U16 group. Already, for the U14 group, performance as only correlated significantly with APHV (r= -0.426, p< 0.05). Moreover, in both U14 and U16 groups there were significant correlations between performance and the years of practice (r_s= -0.240, p< 0.05 and r_s= -0.375, p< 0.01, respectively), the sitting height (r_s= -0.314 and r= -0.375, p< 0.05, respectively) and the maturity offset (r_s= -0.261, p< 0.01 and r= -0.493, p< 0.05, respectively). López-Plaza et al. (2016) found that chronological age (r= -0.720, -0.600 and -0.712), height (r= -0.495, -0.433 and -0.510), sitting height (r= -0.514, -0.622 and -0.643), body mass (r= -0.441, -0.325 and -0.423), and maturity offset (r= -0.628, -0.674 and -0.731) were all significantly (p< 0.01) correlated with the performance at 1000, 500 and 200 m, respectively. Forbes et al. (2009) have also reported that age (r= -0.59), height (r= -0.81), and sitting height (r= -0.85) were all significantly (p< 0.05) correlated to 1000 m performance. About sitting height, it should be noted that coaches and athletes may try to alter the boat set-up in order to counteract a possible lower sitting height, namely rising the boat seat height of the kayaker. However, this fact can influence the mechanical efficiency of the paddling technique (Broomfield & Lauder, 2015) and probably demand for a longer paddle, which, initially, can lead to a reduction in boat speed (Ong et al., 2006).

The distances analyzed in this investigation were different in comparison with previous studies. That fact cannot be ignored since the requirements and specificities of the effort are different. Also, the 1000 m trials are typically carried out in a straight line, whereas the long distance such as the 3000 and 5000 m are performed in a circuit, which may imply a more significant influence of chance on performance. In-circuit events, athletes can navigate in groups on watercourses with variable width and depth and with the need to go around the buoys several times. Thus, increasing the probability of the occurrence of a misfortune such as capsize the vessel, fail the number of laps, shortcut or increase the route distance or breaking the rudder. Also, the present study has as limitations the impossibility of assessing all competition' participants. In addition, the specific nature of the competition, ability to ride the opponent's wave, tactical decision-making, problems due to equipment malfunction (paddle and kayak), and the fact that there was a qualifying event on the morning of the competition may all have negatively influenced performance.

4.7. Conclusions

The involvement of children in competitive sports today is a widespread and multifaceted reality. Thereby young athletes are subjected to considerable changes that determine different effects on training and performance. There are two ways in which young athletes can improve their performance: training and growth.

This research has shown differences in the maturity status of young U14 and U16 kayakers, identifying that the more biologically mature individuals were also those who revealed larger bodies and best kayaking performances. Also, the kayakers with more years of specific practice were the ones that achieved better performances.

Despite focusing on populations that compete in Spain and Portugal, this study is unique because it attempts to assess all the participating kayakers in the competition and evaluate competitions held in circuits that carry distinct particularities. In contrast, previous studies have considered only the best in their categories in straight-line competitions. Kayaking is a sport where technical ability seems to be critical, and technical skills may influence performance. Future studies should consider the possibility of evaluating the technical skills of the athletes and assessing larger samples. It would also be interesting if future investigations focused on the relative age effect in kayaking and tactical decision-making in-circuit competitions. To conclude, it is essential to focus on youth athletes' potential to develop towards expert performance. The present study's findings underline the relevance of creating evaluation batteries that behold maturity status and years of specific practice information.

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CHAPTER V: Study 3

5. Maturity status, relative age and constituent year effects in young Iberian kayakers

Reference: Fernandes, R.A., Gomes, B.B., & Alacid, F. (2022). Maturity Status, Relative Age and Constituent Year Effects in Young Iberian Kayakers. Applied Sciences, 13(1), 560. https://doi.org/10.3390/app13010560

5.1. Abstract

Like in other sports systems, in kayaking, young athletes are commonly grouped by their birth years. This study analyzed maturity status, relative age, and constituent age effects in young Under 14 (U14) and 16 (U16) Iberian male kayakers. One hundred thirty (U14: n =80; U16: n = 50) young kayakers aged 14.10 ± 1.06 years were assessed for anthropometry, performance, maturity, and sport experience. The year was divided into four birth quarters (BQ). There were no significant differences in the kayaker's distribution by BQ in both categories (U14, $p = 0.348$; U16, $p = 0.709$) or total sample ($p = 0.783$). Six of the ten best kayakers in the U14 category were born in the year's first half, and eight were among the U16 kayakers. Talent detection and selection systems based solely on the young kayakers' performances may imply some bias. One of the ways to get around this situation would be to adopt a grouping system similar to bio-banding, allowing the maximum number of practitioners to experience the possibility of obtaining competitive success.

Keywords: Talent identification; maturation; performance; kayaking.

5.2. Introduction

In Portugal and Spain, during the various age-group competitions, different experience levels and skill may be found among the paddlers participating in the National Championship. To provide equal opportunities during competition, like in other sports systems, in kayaking, young athletes are commonly grouped by their birth year.

Maturation is a process that involves many body changes (Baxter-Jones et al., 2005). It plays a crucial role in improving motor skills; and maximizing motor skill proficiency is ideal in childhood (Myer et al., 2011). Previous research, considering performance (Medic et al., 2007), with young paddlers has focused on maturational and morphological analysis of the best athletes in their categories (Altimari et al., 2021; Sandercock et al., 2014; Sherar et al., 2007; Wattie et al., 2015), and reported that the most mature kayakers obtain the best performances. More recently, Fernandes et al., (2021) showed that years of practice were crucial in youth kayaking success besides maturity. Therefore, talent identification batteries must consider aspects of maturity in performance variations (Lloyd et al., 2017), preventing the drop out of less mature children derived from a absence of competitive success or a perceived absence of ability (Delorme & Raspaud, 2009b).

Meanwhile, relative age (RA) concerns a child's chronological age inside their age group and is defined by the date of birth and the cut-off selection date (Parr et al., 2020). The relative age effect (RAE) is a frequent occurrence in youth sports (Kearney et al., 2018) and is characterized by the discrepancy between athletes' observed and expected birth date distributions (Figueiredo et al., 2019). Thereby, children born early in the selection year have more probability of experiencing successful participation and maintaining it.

It's important to notice that RA and biological maturation are independent constructs. RA depends on birth and cut-off dates, and biological maturation depends on genetics and environmental context. Also, there is a considerably more extensive range for variation in biological maturity in a single-year age group than in RA. While in RA, differences are limited to twelve months, maturity can differ up to six years (Parr et al., 2020).

For instance, regarding chronological age, a person born in January is nearly twelve months older than some other person born in December's same year. Consequently, the physical and psychological differences that can be observed may perhaps be attributed to this singularity (Cobley et al., 2009; Wattie et al., 2015). Furthermore, when studying under 13 and 15 football players, Altimari et al.

(Altimari et al., 2021) stated that stature, body mass, and lean body mass were influenced by the birth date in these categories. Additionally, Sandercock et al. (Sandercock et al., 2014) presented significant differences between birth months in an analysis of physical fitness test performances. Such an advantage could justify, to some extent, the bias in sports selection credited to the peculiarities of the RAE.

Also, RAE may show up well before puberty, and it is more likely that these differences result from the context in which children are inserted, resulting in the possibility of experiencing different environments with implications for their development, which is probably more associated with age than maturity (Sherar et al., 2007). For that reason, almost all competitive sports are organized into age categories, presumably, to reduce such differences. Most likely, participants are grouped by chronological age to guarantee honest competition and opportunity (Medic et al., 2007).

The influence of relative age effect phenomena is explained as influencing several sports, including swimming (Baxter-Jones, 1995; Costa et al., 2013), football (Sierra-Díaz et al., 2017), and basketball (Arrieta et al., 2016). Nevertheless, reversed RAE has also been reported, like in the cases of athletics (Brustio et al., 2019) and futsal (Lago-Fuentes et al., 2020). Moreover, this inverse RAE has been explained in sports where performance demands high technical skills (Romann & Fuchslocher, 2014), and physical qualities may be secondary (Delorme & Raspaud, 2009a).

Regarding kayaking, the only study focusing on the RAE phenomena was conducted by Isorna-Folgar et al. (2014), pointing out that young athletes born in January, February, and March have more probability of being chosen for development training camps. However, more is needed to configure certainty about achieving international sporting success in later years. Indeed, youngsters with the potential to reach the elite level born late in the year have an inferior opportunity to participate in sports when they have already passed puberty (Baxter-Jones & Helms, 1994). In most sports, children born early in the year have better performances than children born later in the year. However, this tendency is not found in adult athletes, with no clear correlation between performance and date of birth (Jakobsson et al., 2021).

Besides the RAE, another fact that may influence performance is the Constituent Year Effect (CYE). This term refers to the effects of the birth year observed in groups with more than one age group (Wattie et al., 2008). During the youth training process, the older athletes of the category tend to have an advantage over the younger ones. This advantage is accentuated mainly due to the physical differences resulting from the maturation processes.

This study intended to analyze maturity status and the RAE, and to evaluate the influence of CYE in young Iberian male kayakers, considering how it may impact the opportunities equity of the young kayakers in the complex and frail system of identification, detection, selection, and development of young kayaking talents.

5.3. Materials and methods

Participants

This study evaluated 130 young Iberian male kayakers aged 14.10 ± 1.06 years born between January 1st of 2003 and December 31st of, 2006. Data was collected regarding kayakers' experience, anthropometry, performance, and maturity status. All participants passed the mandatory medical examinations required by the respective national federation. Kayakers with less than one year of practice were automatically excluded from the assessment. The Ethical Committee approved all procedures. Written informed consent was obtained from parents or legal guardians.

Design and procedures

To assess RAE, kayakers born between January 1st of 2003 and December 31st of 2004, were categorized as under 16 years of age (U16). Kayakers born between January 1st of 2005, and December 31st of 2006 were classified as under 14 years of age (U14). Uniformity of birth season of broader populations from different regions was assumed. Birth quarters (BQ) were defined as 1st BQ: January 1st to March 31st, 2nd BQ: April 1st to June 30th, 3rd BQ: July 1st to September 30th and 4th BQ: October 1st to December 31st. To assess the CYE, the athletes were also divided by year of birth (Medic et al., 2007). The participants were distributed as follows: 50 U16, 15.24 ± 0.61 years, 80 U14, 13.40 ± 0.54 years.

Data were collected at the Spanish and Portuguese National Championships, and the competitions took place with about a month of difference. Racecourse conditions were flat water with no current alongside good weather with no wind (less than 0.5 $m.s^{-1}$), which were verified in both competitions. Kayakers were assessed considering their competition schedule and throughout the day.

Two certified level 3 International Society for the Advancement of Kinanthropometry (ISAK) evaluators took all anthropometric measures following the ISAK procedures. Body mass (kg) was assessed using a digital scale SECA 878 (SECA, Germany), stretch stature, and sitting height (cm) with a portable stadiometer SECA 206 (SECA, Germany). Before the sessions, to prevent measurement inaccuracies, all instruments were calibrated. Relative technical error of measurement (Perini & de Oliveira, 2005) ranged between 0.03% and 0.11% for anthropometric measures.

For performance, the competition officials considered the time, in seconds, required for the kayakers to complete the race, 3000 and 5000 m for the U14 and U16, respectively. Also, the distribution of birth quarters of the participants who obtained the ten best performances in each category was analyzed.

Biological development was assessed by somatic maturation (Baxter-Jones et al., 2005), the percentage of the predicted adult height (PAH%) defined the maturity status, and the Khamis & Roche, (1994) method was used to estimate the paddlers predicted adult height (PAH). Mean parental stature was corrected according to Epstein et al. (1995). Also, maturity offset was obtained to estimate the distance in years from the peak growth velocity for height (PHV), that the athlete is currently in (Mirwald et al., 2002). Kayakers were classified as late, on time (average), or early maturing based on the PAH% converted to a z-score (Figueiredo et al., 2019; Malina et al., 2012; Myburgh et al., 2019). A z-score between − 1.0 and + 1.0 categorized the kayaker as on time in maturity status. A z-score < − 1.0 classified the kayaker as late, while a z-score > + 1.0 classified the kayaker as early maturing (Myburgh et al., 2019).

5.4. Statistical analysis

The data distribution and the homogeneity of variance were tested using Kolmogorov–Smirnov and Levene's, respectively. Birth year intervals (frequency) and distributions of kayakers by maturity status were determined by BQ for all kayakers and evaluated with the Chi-square statistic. Descriptive statistics were determined by BQ in each category and by year of birth and compared with one-way analysis of variance (ANOVA) with post hoc Bonferroni test. Estimated effect sizes (η2) were also calculated. The level of significance was set as $p < 0.05$. SPSS Statistics 27.0 (SPSS Inc., Chicago, IL) was applied to perform the statistical analysis.

5.5. Results

The frequency of month and years of birth by quarter of the young Iberian kayakers, for U14, 16, and the total sample are summarised in Table 5.1. There were no significant differences in the kayakers' distribution by BQs, for the category of participation (U14, $p = 0.348$; U16, $p = 0.709$) or total sample ($p = 0.783$). Despite that, when analyzing the total sample, the kayakers born in the 3rd BQ were slightly more represented (28.5%). Examining by category of participation, this tendency was observable only for the U14, where the athletes born in the 3rd BQ represented 37.3% of all the participants. For the U16 category, the tendency was to observe more paddlers born in January, February, and March.

Maturity status distribution was significant for the total sample in both categories and was also significant regarding U16 kayakers born in 2003 and 2004 and U14 kayakers born in 2005 (Table 5.2).

About the ten best kayakers in each category, three U14 kayakers were born in 2006 and seven in 2005. In the U16, two kayakers were born in 2004 and eight in 2003. Four early maturers were among the top ten performers in both categories. All early maturers in the U14 category were born in 2005, with three born in the first two BQ's. In the U16, all four were born in the first two BQ's. Also, regarding the U16 kayakers, seven early maturers were observed in the total sample (n= 50); six were born in 2003, and five in the 1st and 2nd BQ's.

Table 5.1. Frequency of month and year of birth by quarter for U14, 16 and the total sample of kayakers.

Age Group	n	Birth year	Mean ± SD CA (years)	1st BQ		2nd BQ		3rd BQ		4th BQ		Expected Frequency	χ^2
				n	%	n	%	n	%	n	%		
U14 Kayakers	80	2006, 2005	13.40 ± 0.54	18	22.5	17	21.3	27	33.8	18	22.5	20	3.300 (ns)
	29	2006	12.82 ± 0.32	8	27.6	6	20.7	8	27.7	7	24.1	7.3	0.379 (ns)
	51	2005	13.73 ± 0.29	10	19.6	11	21.6	19	37.3	11	21.6	12.8	4.137 (ns)
U16 Kayakers	50	2004, 2003	15.24 ± 0.61	15	30.0	12	24.0	10	20.0	13	26.0	12.5	1.040 (ns)
	26	2004	14.73 ± 0.32	8	30.8	5	19.2	5	19.2	8	30.8	6.5	1.385 (ns)
	24	2003	15.78 ± 0.26	7	29.2	7	29.2	5	20.8	5	20.8	6	0.667 (ns)
Total Sample	130	2006, 2005, 2004, 2003	14.10 ± 1.06	33	25.4	29	22.3	37	28.5	31	23.8	32.5	1.077 (ns)

CA: chronological age; BQ: birth quarter; (ns): non-significant.

Considering the kayakers' characteristics by BQ and year of birth, Tables 5.3. and 4 summarise the data from the U14 and U16 athletes, respectively. Table 3 shows that, regardless of CA, whoever has more years of practice obtains the best performances despite the maturational status. In the U16 category (Table 5.4.), the kayakers born in the 1st BQ were significantly ($p < 0.05$) older than the athletes born in the 4th BQ, F(3; 46) = 6.294, $p = 0.001$, η2 = 0.29. So naturally, these kayakers were observed as taller (174.06 ± 6.66 cm), F(3; 46) = 0.713, $p = 0.549$, η2 = 0.04, heavier (66.09 ± 8.40 kg) F(3; 46) = 0.946, $p = 0.426$, η2 = 0.06, and also fastest (1406.16 ± 75.29 s), F(3; 46) = 2.313, $p = 0.088$, η2 = 0.13. However, they do not present themselves as being the most mature. That characteristic was verified in the athletes born in the 2nd BQ (96.70 ± 1.13 PAH%).

Kayakers born in 2003 were significantly (p < 0.05) more mature (97.38 ± 0.8%), F(1; 48) = 56.353, $p = 0.000$, η2 = 0.54, and more experienced (5.06 ± 2.00 years), F(1; 48) = 11.456, $p = 0.001$, η2 = 0.19, than those born in 2004 (94.85 ± 1.44 %, 3.25 ± 1.77 years). They, consequently, obtained the best performances.

Table 5.2. Distributions of the kayakers' maturity status based on PAH% by BQ for the total sample of U14 and 16, top ten U14 and 16, and CYE (U14, 2005; 2006 and U16, 2003; 2004).

	BQ of U14 total sample					BQ of U14 top ten					BQ of kayakers born in 2006					BQ of kayakers born in 2005				
	1st	2nd	3rd	4th	χ^2	1st	2nd	3rd	4th	χ^2	1st	2nd	3rd	4th	χ^2	1st	2nd	3rd	4th	χ^2
Maturity status U14	n= 18	n= 17	n= 27	n = 18		n= 1	n= 5	n= 4	n= 0		n= 8	n= 6	n= 8	n= 7		n= 10	n= 11	n= 19	n= 11	
PAH%:																				
Early	5	2	2	0		1	2	1	0		0	0	0	0		5	2	2	0	
On time	13	11	18	14		0	3	3	0		8	4	4	4		5	8	14	11	
Late	0	4	7	4	49.075 (*s*)	0	0	0	0	0.400 (*ns*)	0	2	4	3	2.793 (*ns*)	0	1	3	0	35.765 (*s*)
	BQ of U16 total sample					BQ of U16 top ten					BQ of kayakers born in 2004					BQ of kayakers born in 2003				
Maturity status U16	n= 15	n= 12	n= 10	n= 13		n= 5	n= 3	n= 0	n= 2		n= 8	n= 5	n= 5	n= 8		n= 7	n= 7	n= 5	n= 5	
PAH%:																				
Early	5	1	0	1		3	1	0	0		1	0	0	0		4	1	0	1	
On time	9	11	8	8		2	2	0	2		6	5	3	4		3	6	5	4	
Late	1	0	2	4	33.640 (*s*)	0	0	0	0	0.400 (*ns*)	1	0	2	4	17.154 (*s*)	0	0	0	0	6.000 (*s*)

PAH: predicted adult height; BQ: birth quarter; (*s*): significant; (*ns*): non-significant

Table 5.3. Characteristics (means and standard deviations) of U14 kayakers by birth quarter (n=80), year of birth (2006, n=29 and 2005, n=51) and results of ANOVA, and estimated effect sizes (η²).

	1st BQ (n=18)	2nd BQ (n=17)	3rd BQ (n=27)	4th BQ (n=18)			Born in 2006 (n=29)	Born in 2005 (n=51)		
Variables	Mean (± SD)	Mean (± SD)	Mean (± SD)	Mean (± SD)	F	η2	Mean (± SD)	Mean (± SD)	F	η2
CA (years)	13.69 ± 0.53*	13.47 ± 0.49*	13.39 ± 0.46	13.03 ± 0.50	5.464	0.18	12.82 ± 0.32†	13.73 ± 0.29	162.093	0.68
Years of practice (years)	3.33 ± 1.46	3.64 ± 1.69	3.25 ± 1.54	2.97 ± 1.13	0.618	0.02	3.41 ± 1.52	3.22 ± 1.44	0.302	0.00
Stretch stature (cm)	164.43 ± 7.68	163.65 ± 10.44	163.45 ± 10.07	163.60 ± 8.81	0.043	0.00	159.49 ± 9.77†	166.17 ± 8.02	10.907	0.12
Sitting height (cm)	85.05 ± 4.43	85.81 ± 5.45	85.18 ± 5.89	86.08 ± 3.71	0.186	0.01	83.54 ± 5.04†	86.59 ± 4.64	7.478	0.08
Body mass (Kg)	55.26 ± 11.24	55.89 ± 8.55	52.75 ± 10.96	57.53 ± 11.82	0.765	0.03	52.34 ± 10.87	56.60 ± 10.43	2.986	0.04
Maturity offset (years)	0.03 ± 0.69	0.02 ± 0.81	-0.12 ± 0.91	-0.13 ± 0.62	0.272	0.01	-0.59 ± 0.66†	0.24 ± 0.67	28.985	0.27
APHV (years)	13.66 ± 0.56	13.44 ± 0.66	13.52 ± 0.71	13.17 ± 0.46	1.999	0.07	13.41 ± 0.64	13.48 ± 0.63	0.248	0.00
PAH (cm)	180.75 ± 5.81	181.62 ± 8.17	182.18 ± 6.22	183.63 ± 6.53	0.593	0.02	182.12 ± 7.43	182.03 ± 6.17	0.003	0.00
PAH (%)	90.94 ± 2.13	90.06 ± 3.04	89.66 ± 3.20	89.07 ± 3.31	1.265	0.05	87.52 ± 2.81†	91.25 ± 2.17	43.809	0.36
3000 m time (s)	915.01 ± 124.53	864.82 ± 124.86	843.24 ± 109.86	871.43 ± 103.55	1.413	0.05	861.77 ± 108.32	875.18 ± 121.28	0.244	0.00

CA: chronological age; APHV: age at peak height velocity; PAH: predicted adult height; BQ: birth quarter. *Significant difference ($p < 0.05$) compared to 4tu BQ. †Significant difference ($p < 0.05$) compared to born in 2005.

Table 5.4. Characteristics (means and standard deviations) of U16 kayakers by birth quarter (n=50), year of birth (2004, n=26 and 2003, n=24) and results of ANOVA, and estimated effect sizes (η^2).

	1st BQ (n=15)	2nd BQ(n=12)	3rd BQ (n=10)	4th BQ (n=13)			Born in 2004 (n=26)	Born in 2003 (n=24)		
Variables	Mean (± SD)	Mean (± SD)	Mean (± SD)	Mean (± SD)	F	η2	Mean (± SD)	Mean (± SD)	F	η2
CA (years)	15.58 ± 0.50*	15.43 ± 0.52*	15.10 ± 0.56	14.77 ± 0.52	6.294	0.29	14.73 ± 0.32†	15.78 ± 0.26	154.055	0.76
Years of practice (years)	4.00 ± 1.42	4.62 ± 2.16	3.95 ± 3.16	3.92 ± 1.78	0.299	0.02	3.25 ± 1.77†	5.06 ± 2.00	11.456	0.19
Stretch stature (cm)	174.06 ± 6.66	170.99 ± 4.34	171.89 ± 6.72	172.63 ± 4.34	0.713	0.04	171.96 ± 5.37	173.12 ± 5.87	0.531	0.01
Sitting height (cm)	91.89 ± 3.98	90.00 ± 3.17	89.84 ± 3.82	90.83 ± 2.93	0.937	0.06	90.20 ± 3.13	91.34 ± 2.94	1.312	0.03
Body mass (Kg)	66.09 ± 8.40	62.09 ± 5.41	63.18 ± 7.23	62.76 ± 5.34	0.946	0.06	62.05 ± 6.85	65.45 ± 6.38	3.272	0.06
Maturity offset (years)	1.97 ± 0.74	1.59 ± 0.48	1.41 ± 0.64	1.36 ± 0.55	2.674	0.15	1.25 ± 0.58†	2.00 ± 0.49	23.430	0.33
APHV (years)	13.61 ± 0.53	13.83 ± 0.55	13.68 ± 0.57	13.40 ± 0.39	1.508	0.09	13.48 ± 0.57†	13.78 ± 0.42	4.545	0.09
PAH (cm)	180.07 ± 4.85	176.83 ± 4.52	180.02 ± 7.31	181.93 ± 4.54	1.987	0.12	181.30 ± 5.30†	178.11 ± 5.19	4.602	0.09
PAH (%)	96.64 ± 1.83	96.70 ± 1.13	95.50 ± 1.77	95.25 ± 1.74	2.633	0.15	94.85 ± 1.44†	97.38 ± 0.82	56.353	0.54
5000 m time (s)	1406.16 ± 75.29	1455.37 ± 102.20	1497.72 ± 80.11	1464.11 ± 89.81	2.313	0.13	1489.25 ± 94.59†	1409.46 ± 65.37	11.845	0.19

CA: chronological age; APHV: age at peak height velocity; PAH: predicted adult height; BQ: birth quarter. *Significant difference ($p < 0.05$) compared to 4tu BQ. †Significant difference ($p < 0.05$) compared to born in 2003.

5.6. Discussion

This study's main objective was to analyse maturity status, the RAE, and to evaluate the influence of CYE in young Iberian male kayakers. As a result, the main findings of this study were that in the U14 (n = 80), unlike the U16 (n = 50), the maturational status does not seem to be a decree of competitive success. So, the CYE appears to influence the performance only in the U16 category. Also, no statistically significant differences were found for the RAE in the total sample (n =130) or the two categories assessed. Nevertheless, a substantial part of the ten best kayakers of each category was born between January and June and were early maturers.

The present study showed that the older U16 kayakers born in the 1st BQ achieved better performances than their peers born in other BQ's. On the contrary, the fastest kayakers in the U14 category were born in the 3rd BQ. Furthermore, those with more years of practice obtained the best performances in both cases. Recently, Fernandes et al. (2021) stated that the young kayakers who achieved better performances were maturely advanced and had more years of specific practice. Moreover, López-Plaza et al. (2016) showed negative and significant correlations between performance and chronological age and presented significant performance maturity-based differences at 1000, 500, and 200 m.

The relative age effect is properly documented in team sports, mainly soccer (Altimari et al., 2021; Figueiredo et al., 2019; Müller et al., 2018; Parr et al., 2020). However, the same does not occur for kayaking, where the RAE phenomenon is practically unstudied. For example, Isorna-Folgar et al. (2014) reported that 37.5% of the paddlers who participated in the Spanish National Training Camps were born in the 1st BQ; however, those who achieved medals in World Championships or Olympic Games were born in the 4th BQ (35.1%). Moreover, analyzing the fifteen male Iberian kayakers who participated in the Tokyo Olympics, eleven were born in the 3rd and 4th BQ, five in the 3rd BQ, and six in the 4th BQ. This fact, associated with the need for technical mastery that kayaking imposes, can explain why the RAE may not be observed at the senior elite level. However, there is the possibility of finding an inverse RAE. In the beginner categories, it is more likely to find RAE than in older age groups. The clarification may be related to the APHV and the age at which puberty occurs, which may undeniably increase the variances in physical traits between athletes born in different BQ's of the same year (Ferriz-Valero et al., 2020).

With 56.3%, the U14 (13.40 ± 0.54 years) has shown a higher percentage of births in the 3rd and 4th BQ's, 33.8% in the 3rd BQ alone. Interestingly, this percentage increases to 37.3% when looking only at the U14 (13.73 ± 0.29 years) born in 2005. On the other hand, in the U16 total sample (15.24 ± 0.61 years), 54% were born in the first two BQ's and 30% in the 1st BQ alone. It was also found that 58.4% of kayakers born in 2003 (15.78 ± 0.26) were born in the first two BQ's. The 3rd BQ was where the highest number of kayakers in the total sample (n=130) were born (28.5%).

Considering the CYE, in the U14 category, significant differences ($p < 0.05$) were observed between athletes born in 2006 and those born in 2005 for CA, stretch stature, sitting height, maturity offset, and PAH%. Although, these were not only not reflected in significant differences in performance, as the younger kayakers were the ones with better performances. This fact may be due to the possibility that the differences mentioned above were masked by the years of practice, 3.41 ± 1.52 years in athletes born in 2005 and 3.22 ± 1.44 years in athletes born in 2006. Moreover, it is known that young kayakers usually obtain the best performances with more years of specific practice (Fernandes et al., 2021).

Another explanation may be the fact that despite the 2005-born kayakers (13.73 ± 0.29 years) being practically a whole year older than the ones born in 2006 (12.82 ± 0.32 years), both were still relatively close to the PHV, 0.24 ± 0.67 and -0.59 ± 0.66 years, respectively. The fact is consistent with the 87.52 ± 2.81 PAH% for the kayakers born in 2006 and 91.25 ± 2.17% for those born in 2005, indicating that the U14 kayakers were somewhat in the early stages of the maturation process. As stated by Cumming et al. (2017), concerning data for soccer players, the majority of players with a PAH% ≥85.0 to <90.0% are early pubertal, and players with a PAH% ≥90.0 to <95.0% are mid-pubertal and players with a PAH% ≥95.00% are late pubertal.

Considering the U16 category and following the same rationale, it was found that athletes born in 2003 were significantly older (15.78 ± 0.26 years) and significantly further away from the PHV (2.00 ± 0.49 years), consequently being closer to their predicted adult height. Additionally, the ones with significantly best performances (1409.46 ± 65.37 s) were significantly more experienced (5.06 ± 2.00 years). These data for U16 kayakers corroborate previous findings (Fernandes et al., 2021; López-Plaza et al., 2016), reaffirming the importance of controlling for maturation at this kayakers' sports development stage.

When performing correlations, comparisons, and regressions, CA is usually a significant variable in kayaking (Alacid et al., 2011; Fernandes et al., 2021; López-Plaza et al., 2016). Thus, those born earlier in the year probably present superior stretch stature, body mass, sitting height, muscle mass, and kayaking experience and possibly obtain better performances.

Moreover, in a sport that presents difficulties in retaining athletes at the senior levels, it is essential to consider the implications of these facts in the early dropout of kayaking. Gardner et al. (2017) state that it is possible to predict young athletes' dropout using enjoyment and behavioural intentions as indicators. Usually, young athletes born in the same year follow the same training programs, and those born in later BQ's often feel frustrated when attaining worse sports results. However, the lack of sports success is one of the factors that leads youth athletes to drop out. Under these circumstances, coach and parental support are essential to persuade the adolescent to continue the sporting activity despite a temporary lack of sports success. Therefore, youth sport is complex. Kayaking is no different, with the addition that it takes place in various water planes and the need for practitioners to move in unstable boats with the same characteristics as those used by senior athletes. Therefore, a talent detection and selection system based solely on the young kayakers' performances may imply some bias. Once, it could confer some competitive advantage to individuals who, by chance, are maturely advanced or have been born earlier than their peers. This study is not without limitations. For example, a study limitation is the assumption of a uniform birth season of broader populations and age sub-groups from different regions. Similarly, despite an effort to evaluate all the U14 and 16 kayakers participating in the competition, the sample size is still limited, so data must be interpreted cautiously.

5.7. Conclusions

Given the constraints that maturation issues impose during the different stages of an individual's growth to adulthood, all categories have their specificity. The U14 and U16 male categories are particularly susceptible to these issues, as they are categories where more significant maturational differences can be observed. As demonstrated by the main findings in this study, namely in the U16 category, the CYE and the maturity status seems to influence the performance, which could imply rethinking how young kayakers are distributed in the category of participation, looking to find a new format that provides equity in kayaking participation. For example, in Portugal and Spain, U14 and U16 kayakers are sub-grouped by year of birth, with the older kayakers categorized as group A and the youngest as group B. One way of refining this form of distribution of participants would be to adopt a grouping system similar to the bio-banding suggested by Cumming et al., (2017)

Additional strategies may include selecting athletes to integrate training groups or primary teams to achieve immediate performances (first team) and other training or secondary teams to develop the athletes to obtain the best performances in the medium to long term. Future studies may also consider including motivational and behavioral variables and training environments, such as social context, coach and parental support, coach experience, peer acceptance, enjoyment, quality of the training sessions, and previous training experiences in other sports.

Therefore, trying to ensure that coaches and sports decision-makers do not make swift decisions and guarantee equal opportunities for young kayakers at different stages of maturational development as much as possible. Thus, allowing the maximum number of practitioners to experience an enjoyable sporting environment with the possibility of obtaining competitive success.

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CHAPTER VI: Study 4

6. Designing an Evaluation Battery for Young Male Kayakers: What variables do you choose?

6.1. Abstract

This study aimed to determine the variables that better explain the performance of young male kayakers at 200 and 500 m in two different categories, U14 and U16, and to identify whether stroke rate (SR), as described for older athletes, is also a determinant factor in performance in these categories. Twenty-four young Iberic kayakers (Portuguese and Spanish), 13.63 ± 1.50 years, distributed in two competitive categories, U14 (12.67 ± 0.47 years), U16 (15.57 ± 0.73 years), were evaluated in terms of training, maturity, anthropometry, limb volumes, body composition, equipment, physical fitness, balance, and performance. Water-shoulder distance correlated significantly in both categories in the two test distances, and U14 and U16 are two different categories, probably severely affected by kayaking experience and maturity-based differences that influence all other variables. These results suggest the need to produce a specific evaluation battery for U14 that includes the water shoulder distance, the 20 m shuttle run test, and the BESS test. And another one for U16 that consists of the water shoulder distance, the pull-up test, and the sit-up test. This study also highlights the importance of designing training programmes capable of providing young kayakers with the ability to perform the paddle technique with maximum efficiency at high SR.

Keywords: Physical fitness; young kayakers; performance; equipment; stroke rate.

6.2. Introduction

Excellence is the main goal of various art forms and also in sports. Thus, talent identification implies recognising, in individuals already involved in sports, the potential to achieve excellence (Williams & Reilly, 2000). However, not many theories in sports are as disruptive as the perception of natural talent (Baker et al., 2019). As a result, the study of key elements of successful sports is now an important area of interest (Dessalew et al., 2019).

Sprint kayaking occurs in flatwater courses and races are contested in nine lanes duly marked with nine-metre width at 200, 500, and 1000 m distances. In kayaking, the trunk rotates from a seated position and is mainly an upper body sport (McKean & Burkett, 2010). As a result, kayakers have considerable upper body strength (Akca & Muniroglu, 2008). However, the importance of the contribution of the lower limb to the paddle technique is gaining relevance (Nilsson & Rosdahl, 2016).

Quantifying sports performance is difficult once it is described as a multidimensional construction (Elferink-Gemser et al., 2007), and, in the context of youth sports, it is indispensable that studies attempt to control for maturity (Baxter-Jones et al., 2005). For example, recent studies with young kayakers have shown the influence of chronological age (Gäbler et al., 2021) and biological maturity on performance (Fernandes et al., 2021; López-Plaza et al., 2016). However, numerous questions have emerged about the trainability of young athletes, and the answers are not yet conclusive. Concerning strength, for example, it is known to increase during childhood and adolescence. However, these variations are attributable to gains in muscle mass and the development of the neuromuscular systems. Both the prepubertal child and the adolescent can demonstrate significant increases in muscle strength with resistance training (Matos & Winsley, 2007).

Recently, Kristiansen et al. (2023) when assessing a group of elite junior, U23, and senior kayak paddlers demonstrated that in the bench press, the one-rep-max (1RM) was the best predictor for a 200 m kayaking performance. Furthermore, the increase in the 1RM in bench press has improved the performance of the kayak. Additionally, measuring physical fitness in children and youth has been a topic of interest for physical educators for a long time. Resistance training in youth is reported to have several advantageous effects (Faigenbaum et al., 2009). Gäbler et al. (2021) showed benefits from low-intensity, high-volume strength training regarding the 2000-m performance of young sprint kayakers.

The anthropometric characteristics found in athletes are influenced by the specific constraints of each sport. Many of these traits are caused by heredity but also by training, resulting in very different anthropometric profiles. As a result, coaches and researchers have struggled to adapt athletes' physical and anthropometric profiles to the specificity of the particular sport to carry them to their maximum performance (Gobbo et al., 2002). Similarly, performance may be affected by an incorrect adjustment of the equipment, potentiated by discomfort and, subsequently, the inability to perform the technical movement in perfect conditions (Burke & Pruitt, 2003). In a study with young paddlers, Alacid et al. (2014) showed that paddle length had higher correlations with stretch stature and arm span, and this could indicate that these measures should be used as criteria for determining those paddle dimensions.

Most of the mechanics researches in kayaking focus on stroke rate (SR), displacement per stroke or stroke length (SL), and boat mean velocity analysis (Li, 2017). Furthermore, previous studies with young kayakers (Alacid et al., 2005; Vaquero-Cristóbal et al., 2013) have already evaluated those variables and included the cycle index (CI) as a result of the SL product by velocity, and as an indicator of efficiency and economy of the stroke Costill et al. (1985).

In kayaking, boat speed is the product of SR by the SL (McDonnell et al., 2013). SR is usually presented as strokes per minute (spm), and an increase in SR is associated with a higher mean kayak velocity and, subsequently, better performance (Brown et al., 2011; McDonnell et al., 2013). The ability to increase SR may depend on the physical preparation of the athlete, but also on the dimensions of the paddle and technique.

Therefore, this research aimed to determine the variables that better explain the performance of young male kayakers at 200 and 500 m in two different categories, U14 and U16, and to identify whether SR, as described for older athletes, is also a determinant factor in performance in these categories.

6.3. Materials and methods

Participants and data collection

This study evaluated 24 young Iberic kayakers (Portuguese and Spanish), aged 13.63 ± 1.50 years, and distributed in two competitive categories, U14 (12.67 ± 0.47 years), U16 (15.57 ± 0.73 years), assessed in terms of training, maturity, anthropometry, limb volumes, body composition, equipment set-up, physical fitness, balance, and performance. The inclusion criteria were mandatory participation in competitive kayaking for at least one year and at least two national competitions before the evaluation, approval on the required medical exams, non-smokers, and no alcohol consumption habits. Additionally, written informed consent of parents or guardians was obtained and the approval of the Ethics Committee of the experimental procedures (protocol code CE/FCDEF-UC/00322018) was ensured.

Procedures

Anthropometric assessments were completed early in the morning, followed by field-based physical tests, and the specific on-water performance evaluation was performed on the second day early in a racecourse with flatwater and fair wind conditions.

Maturity status

Somatic maturation was used to evaluate biological development (Baxter-Jones et al., 2005). Maturity offset (Mirwald et al., 2002) is an indicator of temporal distribution and proposes to estimate the distance in years, which the subject is of the peak growth velocity in height (PHV). This value can be negative (if the subject has not yet reached PHV) or positive (if it has already exceeded PHV). Also, the percentage of predicted adult height (PAH%) defined the maturity status, and the athlete-predicted adult height (PAH) was estimated using the method of Sherar et al. (2005) method.

Anthropometry

All measurements were taken following the procedures described by the International Society for the Advancement of Kinanthropometry by an experimented researcher. Body mass (kg) was determined using an SECA 878 (digital scale, SECA, Germany). Stretch stature (cm) and sitting height (cm) were determined with a SECA 206 (Portable stadiometer, SECA, Germany). Arm span (cm) was measured using a metallic tape (Stanley, USA); the arm, forearm and hand lengths (cm), humerus and biacromial breadths (cm) were measured using a sliding calliper (Siber-Hegner GPM Calliper, Switzerland). The relaxed arm, flexed tensed arm, and chest girths (cm) were measured using an anthropometric tape (Lufkin W606PM, USA).

Skinfold thickness (mm) was measured at six sites (triceps, subscapular, supraspinal, abdominal, front thigh, and medial calf) with a Harpenden skinfold calliper (British Indicators, UK), and the percentage of body fat was estimated from the equation defined by Slaughter et al. (1988) using triceps and calf skinfolds.

All instruments were verified and calibrated before the beginning of each testing session to avoid measurement errors, all measurements were taken two or three times (if the difference between the two first measures was greater than 5% in skindfolds and 1% to the rest of measures), and the mean or median was used, respectively. Relative technical error of measurement (Perini et al., 2005) for anthropometric measures ranged between 0.11% and 0.20%.

Limb Volumes

Volumes of the upper and lower extremities were evaluated in the dominant limbs, following the protocol of Rogowski et al. (2008) and Jones & Pearson (1969), respectively.

Equipment setup

For the equipment set-up, the variables measured were the paddle and blade length, blade width, handgrip distance, angle between blades, and seat-footrest distance (cm) (Ong et al., 2005). In addition, vertical water-shoulder distance (cm) was also included.

The paddle length (cm) was measured using metallic tape (Stanley, USA). Blade length (cm), blade width (cm) and handgrip distance (cm) were measured using a sliding calliper (Siber-Hegner GPM Anthropometer, Switzerland). The angle between the blades was measured using a device with a protractor (Smart Protractor version 1.5.8). Finally, the vertical water-shoulder distance was measured using a specially developed apparatus and a laser beam (Bosch, GLM 40 Professional). All measurements were taken two or three times (if the difference between the two first measures was greater than 1%), and the mean or median was used, respectively.

Physical Fitness

The physical fitness of the kayakers was assessed by throwing the overhead medicine ball throw (Gabbett & Georgieff, 2007). Due to the importance of trunk rotation in the paddle technique (Kendal & Sanders, 1992; Michael et al., 2009), an adaptation of this test for lateral medicine ball throws with the kayakers taking a seated position similar to the kayak paddling position. The sit-and-reach test was used to determine hamstring extensibility (Lopez-Miñarro et al., 2013). The multistage 20-m shuttle-run test (Léger & Lambert, 1982) was used. Pull-up, push-up, and sit-up tests were evaluated following the Fitnessgram test battery (The Cooper Institute for Aerobics Research, 1999). The handgrip strength test was used and followed the Eurofit test battery methodology (Council of Europe, 1988) using a dynamometer (Hand Dynamometer - Lafayette model J00105, USA).

Before all physical tests, the investigators provided clear instructions for each procedure. General warm-up consisted of eight minutes of multidirectional running activity and five minutes of general dynamic stretching of the upper and lower extremities delivered and supervised by a certified canoe sprint level 3 coach. During the evaluations, the same sequence of tests was applied. When assessing physical fitness, only the best of three attempts in each trial was considered for analysis, giving at least three minutes of rest between trials, except for the 20-m multistage shuttle run test, which was performed once. The warm-up involved five minutes of familiarity with the materials and procedures used shortly before each test.

Postural Stability

The Balance Error Scoring System (BESS) measures static balance and postural stability. It combines three stances (narrow double leg stance, single leg stance, and tandem stance) and uses two footing surfaces (firm surface/floor or medium density foam). Each stance is held, with hands on hips and eyes closed, for 20 seconds. To any "Error" for specific actions, including opening eyes, lifting hands off hips, or stepping, stumbling, or falling points are given, and a higher total score reflects worse performance on the test (Iverson & Koehle, 2013).

Performance

Performance evaluations were carried out in calm water, without current or significant wind. Participants were asked to complete a 500-m trial, followed by a 60-minute interval and then a 200-m trial. Both trials were carried out in a straight line and in the shortest possible time. Before each test, kayakers were asked to perform their usual pre-race warm-up.

The average SL was calculated following the methodology of (McDonnell et al., 2013), and the time spent to complete both the distances and the SR was obtained using a wireless unit with a 15-Hz GPS and a 3D IMU. This unit contains 12 channel receivers tracking up to 12 satellites, combined with a triaxial accelerometer with a sampling rate of 100 Hz (GPSPORT, Canberra, Australia), fixed on the stern of the kayak deck, synchronising GPS and IMU data. Data were extracted to spreadsheets with Team AMS R1 2016.7 software. Then exported to Matlab® R2019b (The MathWorks Inc., Natick, MA, USA) and analysed using a routine specially developed for this application and already validated (Fernandes et al., 2021).

6.4. Statistical analysis

The data distribution and the homogeneity of variance were tested using Shapiro–Wilk and Levene's, respectively. The Spearman correlation coefficient (r_s) was used to determine the relationships between all variables and performance and SR. Correlations were considered: negligible correlation when 0.3; low correlation when 0.3–0.5; moderate correlation when 0.5–0.7; high correlation when 0.7–0.9 and very high when 0.9–1 (Mukaka, 2012). Group mean comparisons for all variables were evaluated using the Kruskal-Wallis test. Also, the ratios paddle length to handgrip distance (PL:HGD) sitting height to water-shoulder distance (SH:WSD) was calculated. The level of significance was established at $p < 0.05$. SPSS Statistics 27.0 (SPSS Inc., Chicago, IL, USA) was applied to perform the statistical analysis.

6.5. Results

All parameters for categories U14 and U16, and their correlation between performance at 200 and 500 m, are presented in Table 6.1.

Statistically significant differences were found between U14 and U16 for all the variables under study, except APHV, PAH, sum of six skinfolds, percentage of estimated fat mass, angle between blades, postural stability, namely total foam surface total and the test total.

In U14 only years of practice, the hours of training per week, shuttle run, total foam surface total, the BESS test 200 m and CI 500 m were significantly correlated with time to perform 200 and 500 m. The water-shoulder distance the 500 m SR and the 500 m SL, was significantly correlated with the time to perform 200 m and 500 m. Regarding U16, the distance between the water-shoulder distance, the pull-ups and the sit-ups were significantly correlated both with the time to perform 200 m and 500 m, the 200 m SR and the BESS test foam surface total and the 500 m SR were significantly correlated with the time to perform 200 and 500 m.

Concerning SR, the top three performances at 200 m in U14 and U16 were always above the mean SR (U14: 119.33 ± 3.51 and U16: 132.33 ± 2.51 spm) and the bottom three below the mean SR (U14: 101.00 ± 4.24 and U16: 118.66 ± 3.05 spm, the same could be observed for 500 m also in both categories, U14: 100.66 ± 2.30 and U16: 109.66 ± 2.51 spm and U14: 94.00 ± 1.73 and U16: 101.00 ± 1.00 spm, respectively.

Table 6.2. shows the correlation between CA, training, maturity, anthropometry, physical fitness, balance, and performance characteristics, and SR and CI at 200 and 500 m. Regarding training, only in U14 have the years of practise

correlated significantly with 500 m SR, and hours per week correlated significantly with 200 m SR and 500 m SR. Considering the equipment set-up in the U14 the water-shoulder distance correlated significantly with the 500 m SR. The U16 blade width correlated significantly with the 200 m SR and the 500 m SR. For physical fitness, U14 significantly showed correlations between shuttle run and 200 m SR and 500 m SR, and U16 between pull-ups and 200 m SR and 500 m SR, and between sit-ups and 200 m SR and the 500 m SR.

Table 6.1. Mean (± SD) for training, maturity, anthropometry, physical fitness, balance, and performance parameters and their correlation between performance at 200 and 500 m (r_s), in the categories U14 and U16.

	U14 (n= 16)			U16 (n= 8)		
	Mean (± SD)	r_s 200 m	r_s 500 m	Mean (± SD)	r_s 200 m	r_s 500 m
CA (years)	12.67 ± 0.47§	– 0.352	– 0.318	15.57 ± 0.73	– 0.619	– 0.810*
Training						
Years of Practice (years)	2.25 ± 1.00§	– 0.705**	– 0.676**	7.06 ± 1.39	– 0.100	– 0.200
Hours per week (hours)	3.46 ± 1.08§	– 0.778**	– 0.625**	13.75 ± 1.38	– 0.378	– 0.378
Maturity						
Maturity offset (years)	– 0.98 ± 0.82§	– 0.493	– 0.400	1.94 ± 0.51	– 0.071	– 0.310
APHV (years)	13.65 ± 0.65	0.497*	0.394	13.62 ± 0.50	– 0.429	– 0.667
PAH (cm)	181.65 ± 5.69	– 0.056	– 0.132	181.18 ± 7.30	0.024	– 0.071
PAH (%)	86.69 ± 3.03§	– 0.525*	– 0.485	96.87 ± 2.70	– 0.190	– 0.381
Anthropometry						
Body Mass (kg)	46.93 ± 8.73§	– 0.355	– 0.459	71.50 ± 6.10	0.405	0.357
Stretch Stature (cm)	157.49 ± 9.83§	– 0.371	– 0.400	174.90 ± 4.73	– 0.119	– 0.262
Sitting Height (cm)	81.79 ± 5.61§	– 0.566*	– 0.475	91.95 ± 2.36	0.048	0.120
Arm Span (cm)	159.32 ± 10.33§	– 0.354	– 0.399	179.17 ± 6.32	– 0.071	– 0.214
Arm Length (cm)	27.93 ± 1.80§	0.070	– 0.077	31.06 ± 1.63	0.120	– 0.168
Forearm Length (cm)	23.09 ± 1.98§	– 0.272	– 0.334	25.85 ± 1.58	– 0.262	– 0.167
Hand Length (cm)	17.13 ± 1.25§	– 0.518*	– 0.404	18.68 ± 0.64	0.060	– 0.060
Relaxed Arm girth (cm)	22.45 ± 2.49§	– 0.080	– 0.187	28.95 ± 2.24	0.262	0.357
Flexed Tensed Arm Girth (cm)	24.50 ± 2.82§	– 0.019	– 0.137	31.98 ± 2.02	0.286	0.476
Chest Girth (cm)	80.21 ± 5.16§	– 0.473	– 0.610*	97.50 ± 4.01	– 0.071	– 0.024
Humerus Breadth (cm)	6.33 ± 0.48§	– 0.145	– 0.215	7.26 ± 0.30	– 0.096	– 0.192
Biacromial Diameter (cm)	34.23 ± 3.00§	– 0.343	– 0.416	38.92 ± 2.49	0.084	0.275
Limb Volumes						
Arm Volume (cm^3)	1450.99 ± 331.23§	– 0.159	– 0.274	2338.59 ± 275.70	0.071	– 0.024
Forearm Volume (cm^3)	680.80 ± 151.07§	– 0.213	– 0.324	1247.47 ± 186.99	– 0.071	– 0.119
Upper Limb Volume (cm^3)	2131.80 ± 473.02§	– 0.172	– 0.244	3586.06 ± 451.50	– 0.024	– 0.071
Thigh Volume (cm^3)	5963.41 ± 1523.77§	0.035	– 0.132	10004.78 ± 1337.03	0.595	0.500
Leg Volume (cm^3)	1369.97 ± 219.01§	– 0.034	– 0.265	2257.29 ± 320.42	0.190	0.143
Lower Limb Volume (cm^3)	7333.39 ± 1715.58§	0.035	– 0.132	12262.07 ± 1570.20	0.500	0.405
Body Composition						
Sum of Six Skinfolds (mm)	83.78 ± 26.44	– 0.091	– 0.018	82.87 ± 15.43	0.167	0.357
Estimated Fat Mass (%)	18.34 ± 2.91	– 0.044	0.070	17.97 ± 3.36	0.181	0.374
Equipment						
Seat-Footrest Distance (cm)	81.50 ± 6.62§	– 0.112	– 0.276	90.37 ± 3.24	0.563	0.371
Water-Shoulder Distance (cm)	45.31 ± 3.78§	– 0.551*	– 0.732**	54.41 ± 4.13	– 0.771*	– 0.747*
Paddle Length (cm)	196.30 ± 7.07§	– 0.382	– 0.293	209.92 ± 3.19	– 0.024	– 0.263
Blade Length (cm)	45.18 ± 1.14§	– 0.071	0.016	49.43 ± 0.56	0.255	0.332
Blade Width (cm)	14.71 ± 0.60§	0.061	0.105	16.11 ± 0.30	0.847**	0.773**
Angle Between Blades (º)	57.36 ± 10.14	– 0.297	– 0.606*	60.36 ± 7.08	– 0.286	– 0.143
Handgrip Distance (cm)	62.16 ± 7.02§	– 0.265	– 0.124	69.46 ± 4.30	– 0.663	– 0.590
Physical Fitness						
Push-ups (reps)	16.31 ± 5.71§	0.034	0.040	26.00 ± 8.91	– 0.333	– 0.476
Pull-ups (reps)	2.56 ± 2.27§	– 0.390	0.004	11.13 ± 4.67	– 0.831*	– 0.880*
Sit-Ups (reps)	42.63 ± 21.43§	0.134	0.276	74.13 ± 8.35	– 0.846*	– 0.873*
Handgrip Strength (Kg/f)	27.11± 5.43§	– 0.452	– 0.482	52.86 ± 7.49	0.214	0.143
Sit and Reach (cm)	1.21 ± 6.89§	– 0.405	– 0.474	10.43 ± 6.67	– 0.262	– 0.167
Overhead Throw (m)	5.24 ± 1.28§	– 0.694**	– 0.409	9.07 ± 1.58	0.000	– 0.286
Right Lateral Throw (m)	3.18 ± 0.73§	– 0.505*	– 0.483	5.11 ± 1.14	0.120	– 0.072
Left Lateral Throw (m)	2.97 ± 0.82§	– 0.585*	– 0.225	5.22 ± 1.07	0.071	– 0.119
Shuttle Run (courses)	43.43 ± 15.82§	– 0.687**	– 0.741**	79.00 ± 12.79	– 0.265	– 0.482
Postural stability						
Firm Surface Total (n)	4.75 ± 2.56§	0.397	0.398	2.88 ± 1.88	0.528	–0.405
Foam Surface Total (n)	10.06 ± 4.26	0.664**	0.836**	9.75 ± 5.25	0.854**	0.805*
Test Total (n)	14.81 ± 6.29	0.668**	0.756**	12.63 ± 6.73	0.747*	0.699
Performance						
200 m time (s)	59.93 ± 5.42§	–	– 0.693**	45.75 ± 2.80	–	– 0.976**
200 m SR (spm)	112.37 ± 7.43§	– 0.585*	– 0.493	126.25 ± 6.81	– 0.952**	– 0.905**
200 m SL (m)	1.79 ± 0.11§	– 0.711**	– 0.433	2.08 ± 0.05	– 0.395	– 0.479
CI 200 m (n)	6.05 ± 0.78§	– 0.921**	– 0.650**	9.14 ± 0.70	– 0.905**	– 0.929**
500 m time (s)	162.15 ± 12.98§	0.693**	–	126.78 ± 4.80	– 0.976**	–
500 m SR (spm)	98.37 ± 3.70§	– 0.616*	– 0.786**	106.37 ± 5.47	– 0.898**	– 0.874*
500 m SL (m)	1.89 ± 5.87§	– 0.558*	– 0.740**	2.22 ± 0.05	0.500	0.381
CI 500 m (n)	5.87 ± 0.66§	– 0.642**	– 0.859**	8.80 ± 0.35	– 0.500	– 0.595

CA: chronological age; APHV: age at peak height velocity; PAH: predicted adult height; SR: stroke rate; SL: stroke length; CI: cycle index. *Correlation is significant at level $p < 0.05$. ** Correlation is significant at level $p < 0.01$; §Significant difference ($p < 0.05$) between U14 and U16.

Table 6.2. Correlation between CA, training, maturity, anthropometry, physical fitness, balance, and performance characteristics, and SR and CI at 200 and 500 m (r_s).

	U14 (n= 16)				U16 (n= 8)			
	r_s 200 m SR	r_s 200 m CI	r_s 500 m SR	r_s 500 m CI	r_s 200 m SR	r_s 200 m CI	r_s 500 m SR	r_s 500 m CI
CA (years)	– 0.021	0.374	0.153	0.379	0.548	0.643	0.503	0.667
Training								
Years of Practice (years)	0.267	0.796**	0.787**	0.147	0.150	0.200	0.050	– 0.100
Hours per week (hours)	0.511*	0.681**	0.642**	0.793**	0.504	0.252	0.055	– 0.378
Maturity								
Maturity offset (years)	– 0.118	0.676**	0.177	0.576*	0.071	0.048	0.084	0.357
APHV (years)	– 0.009	– 0.650**	– 0.135	– 0.638**	0.452	0.333	0.407	0.500
PAH (cm)	– 0.471	0.318	0.024	0.291	0.143	– 0.095	0.228	– 0.476
PAH (%)	– 0.047	0.659**	0.231	0.650**	0.048	0.286	– 0.132	0.667
Anthropometry								
Body Mass (kg)	– 0.170	0.491	0.121	0.691*	– 0.452	– 0.190	– 0.563	– 0.167
Stretch Stature (cm)	– 0.192	0.597*	0.253	0.526*	0.143	0.119	0.228	0.095
Sitting Height (cm)	– 0.022	0.751**	0.256	0.661**	– 0.108	0.048	0.036	0.120
Arm Span (cm)	– 0.197	0.546*	0.162	0.588*	– 0.024	0.048	– 0.060	0.286
Arm Length (cm)	– 0.460	0.137	– 0.229	0.258	– 0.120	– 0.120	– 0.229	0.048
Forearm Length (cm)	– 0.313	0.494	– 0.209	0.389	0.048	0.381	0.060	0.381
Hand Length (cm)	– 0.051	0.661**	0.138	0.589*	– 0.012	0.120	– 0.030	– 0.156
Relaxed Arm girth (cm)	– 0.283	0.214	– 0.045	0.423	– 0.333	– 0.048	– 0.491	– 0.167
Flexed Tensed Arm Girth (cm)	– 0.336	0.171	– 0.015	0.325	– 0.381	– 0.143	– 0.347	– 0.429
Chest Girth (cm)	– 0.033	0.613*	0.325	0.741**	– 0.024	0.357	– 0.144	0.000
Humerus Breadth (cm)	– 0.381	0.307	0.004	0.410	0.084	0.228	– 0.127	0.012
Biacromial Diameter (cm)	– 0.084	0.544*	0.151	0.597*	– 0.216	– 0.144	0.277	0.192
Limb Volumes								
Arm Volume (cm^3)	– 0.352	0.376	0.119	0.406	– 0.143	0.143	– 0.299	0.071
Forearm Volume (cm^3)	– 0.328	0.435	0.192	0.379	0.095	0.119	– 0.060	– 0.286
Upper Limb Volume (cm^3)	– 0.363	0.397	0.134	0.335	– 0.024	0.190	– 0.132	– 0.095
Thigh Volume (cm^3)	– 0.516*	0.147	– 0.150	0.315	– 0.595	– 0.500	– 0.719*	– 0.190
Leg Volume (cm^3)	– 0.459	0.229	0.046	0.412	– 0.357	– 0.095	– 0.515	0.333
Lower Limb Volume (cm^3)	– 0.516*	0.147	– 0.150	0.315	– 0.524	– 0.381	– 0.683	– 0.143
Body Composition								
Sum of Six Skinfolds (mm)	– 0.241	0.085	– 0.085	0.056	– 0.119	0.024	0.072	– 0.762*
Estimated Fat Mass (%)	– 0.054	0.010	– 0.012	0.093	– 0.133	0.012	0.036	– 0.759*
Equipment								
Seat-Footrest Distance (cm)	– 0.390	0.334	0.126	0.440	– 0.419	– 0.467	– 0.428	– 0.335
Water-Shoulder Distance (cm)	0.218	0.631**	0.499*	0.758**	0.699	0.627	0.618	0.639
Paddle Length (cm)	– 0.197	0.517*	0.132	0.452	– 0.048	– 0.072	0.048	0.407
Blade Length (cm)	– 0.256	0.076	0.100	– 0.003	– 0.511	– 0.089	– 0.475	0.332
Blade Width (cm)	– 0.351	– 0.014	– 0.007	– 0.063	– 0.884**	– 0.724*	– 0.976**	– 0.295
Angle Between Blades (º)	0.361	0.343	0.614*	0.284	0.452	0.143	0.383	– 0.357
Handgrip Distance (cm)	– 0.339	0.431	0.185	0.156	0.819*	0.470	0.830*	– 0.229
Physical Fitness								
Push-ups (reps)	0.162	0.052	0.179	– 0.221	0.548	0.452	0.527	0.548
Pull-ups (reps)	0.322	0.361	– 0.039	0.055	0.868**	0.747*	0.812*	0.578
Sit-Ups (reps)	– 0.044	0.024	– 0.068	– 0.308	0.791*	0.709*	0.851**	0.546
Handgrip Strength (Kg/f)	0.055	0.489	0.254	0.615*	– 0.095	– 0.190	– 0.108	– 0.286
Sit and Reach (cm)	– 0.047	0.462	– 0.019	0.725**	0.238	0.000	0.108	0.381
Overhead Throw (m)	0.263	0.685**	0.158	0.620*	0.095	– 0.095	0.048	0.071
Right Lateral Throw (m)	0.072	0.578*	0.375	0.497*	– 0.204	– 0.084	– 0.422	0.299
Left Lateral Throw (m)	0.122	0.628**	0.043	0.447	– 0.143	0.000	– 0.395	0.643
Shuttle Run (courses)	0.820**	0.541	0.653**	0.553*	0.422	0.386	0.594	0.229
Postural stability								
Firm Surface Total (*n*)	0.103	– 0.500*	– 0.267	– 0.452	– 0.540	– 0.331	– 0.655	– 0.282
Foam Surface Total (*n*)	– 0.307	– 0.666**	– 0.713**	– 0.676**	– 0.732*	– 0.756*	– 0.700	0.146
Test Total (*n*)	– 0.234	– 0.667**	– 0.611*	– 0.683**	– 0.627	– 0.627	– 0.606	0.048
Performance								
200 m time (s)	– 0.585*	– 0.921**	– 0.616*	– 0.642**	– 0.952**	– 0.905**	– 0.898**	– 0.500
200 m SR (spm)	–	0.399	0.414	0.365	–	0.786*	– 0.934**	0.333
200 m SL (m)	0.082	0.908**	0.513*	0.397	0.204	0.743*	0.265	0.323
CI 200 m (*n*)	0.399	–	0.606*	0.612*	0.786*	–	0.766*	0.524
500 m time (s)	– 0.493	– 0.650**	– 0.786**	– 0.859**	– 0.905**	– 0.929**	– 0.874**	– 0.595
500 m SR (spm)	0.414	0.606*	–	0.424	– 0.934**	0.766*	–	0.216
500 m SL (m)	– 0.493	0.582*	– 0.786**	0.958**	– 0.905**	– 0.874**	– 0.874**	0.429
CI 500 m (*n*)	0.414	0.612*	0.424	–	– 0.934**	0.524	0.216	–

CA: chronological age; APHV: age at peak height velocity; PAH: predicted adult height; SR: stroke rate; SL: stroke length; CI: cycle index.

*Correlation is significant at level $p < 0.05$. ** Correlation is significant at level $p < 0.01$.

Table 6.3. shows the mean and standard deviation for the PL:HGD and SH:WSD ratios.

Table 6.3. Mean (± SD) for the PL:HGD and SH:WSD ratios.

	U14 (n= 16)	U16 (n= 8)
	Mean (± SD)	Mean (± SD)
PL:HGD (*n*)	3.18 ± 0.28	3.03 ± 0.18
SH:WSD (*n*)	1.81 ± 0.13§	1.69 ± 0.09

PL:HGD: paddle length:handgrip distance; PL:BW: paddle length:blade width; blade length:blade width and SH:WSD: sitting height:water-shoulder distance
§Significant difference ($p < 0.05$) between U14 and U16.

The SH:WSD ratio revealed statistically significant differences between U14 and U16. Additionally, the three top and bottom U14 performances at 200 m show a SH:WSD ratio below the average for the age group (1.77 ± 0.04 and 1.77 ± 0.06 *n*, respectively). Regarding the three top and bottom U14 performances at 500 m, the observed SH:WSD ratio was below average for the top performances (1.77 ± 0.02 *n*) and above average for the bottom (1.84 ± 0.12 *n*). In the U16 it was observed both in the 200 and in the 500 m performances, an SH:WSD ratio below average for the top performances (1.64 ± 0.06 *n*) and above average for the bottom performances (1.77 ± 0.11 *n*).

Table 6.4. shows the mean and standard deviation for the sitting height (SH), the water-shoulder distance (WSD), and the SH – WSD difference.

Table 6.4. Mean (± SD) for the SH, the WSD, and the SH – WSD difference.

	U14 (n= 16)					U16 (n= 8)				
	Mean (± SD)	Top 3 200 m	Top 3 500 m	Bottom 3 200 m	Bottom 3 500 m	Mean (± SD)	Top 3 200 m	Top 3 500 m	Bottom 3 200 m	Bottom 3 500 m
Anthropometry										
Sitting Height (cm)	81.79 ± 5.61	85.50 ± 7.05	83.37 ± 4.02	81.63 ± 4.67	76.50 ± 2.18	91.95 ± 2.36	92.07 ± 3.75	92.07 ± 3.75	91.30 ± 1.61	91.30 ± 1.61
Equipment										
Water-Shoulder Distance (cm)	45.31 ± 3.78	49.07 ± 2.65	47.30 ± 1.56	46.20 ± 2.51	41.73 ± 2.21	54.41 ± 4.13	56.10 ± 4.53	56.10 ± 4.53	51.57 ± 3.21	51.57 ± 3.21
Difference										
SH–WSD (cm)	36.48 ± 4.39	36.43 ± 4.41	36.07 ± 3.09	35.43 ± 2.30	34.77 ± 3.58	37.66 ± 2.76	35.97 ± 0.96	35.97 ± 0.96	39.63 ± 3.52	39.63 ± 3.52

SH: sitting height; WSD: water-shoulder distance.

6.6. Discussion and implications

This research aimed to determine the variables that better explain the performance of young male kayakers at 200 and 500 m in two different categories, U14 and U16, with the aim of creating more suitable evaluation batteries according to age group. In addition, identify whether SR, as described for older athletes, is a determinant factor in performance in these categories.

The main finding of this study was that only water-shoulder distance correlated significantly in both categories in the two test distances and that U14 and U16 are probably severely impacted by age, kayaking experience and maturity-based differences that influence all other variables. These may reinforce the need to design assessment batteries that accommodate these differences. On the other hand, it is possible to verify that, according to previous studies in adult athletes, a higher SR is effectively correlated with performance in the two distances studied and in the two age categories.

However, it is essential to highlight that the study of young athletes is complex. Many factors contribute to sporting success, making it challenging for coaches and sports scientists to interpret results, mainly because it is difficult to accurately discriminate in growing athletes whether the results are due to training or the maturation process.

The CA, anthropometric, and maturational characteristics are intertwined. Gäbler et al. (2021) showed that CA alone may be responsible for the differences observed in the performance of young paddlers. If an athlete is older or more mature than his peers and has been exposed to the growth process earlier and longer, it may have superior anthropometric characteristics. Also, Fernandes et al. (2022) showed that older U16 kayakers born in the first birth quarter performed better than their peers born in other birth quarters. The fastest kayakers in the U14 category were born in the third quarter of birth.

Furthermore, it seems that those with more years of practise will obtain the best performances, despite the category they compete in, as shown by Fernandes et al. (2021), who stated that the young kayakers who attained better performances were maturely advanced and had more years of specific practice. Forbes et al. (2009) have also reported that age, height, and sitting height were all significantly correlated with 1000-m performance. Likewise, López-Plaza et al. (2016) evaluated young kayakers' anthropometric, physical fitness, and specific performance characteristics. They reported significant differences ($p < 0.05$) based on maturity for body mass, height, sitting height, overhead medicine ball throw, and specific performance tests at 1000, 500, and 200 m. Gäbler et al. (2021) reported that physical fitness tests show a more significant association with performance when they share similarities in biomechanical and physiological terms. In the present study, the right and left lateral medicine ball throw only correlated significantly with the time at 200 m for the U14 category. In U16, the pull-up test correlated significantly with the time required to perform both distances.

The present study shows that only in the U14 have maturity indicators significantly correlated with performance and only with 200 m, which also may indicate kayaking experience as a levelling factor between kayakers with different maturity levels, reinforcing the technical nature of the sport and possibly the importance of strength to performance, especially in 200 m.

The significant correlation between the total score of the BESS test and the performances of U14 on both 200 and 500 m and by U16 on 200 m may reinforce the notion that in kayaking, much of the ability to execute the technique correctly can be attributed to the athlete's stability. However, with respect to the total score of the BESS test, it was possible to verify that significant and negative correlations were observed between the SR and the CI in 200 and 500 m, only in the U14 category. The nonverification of this significant correlation in the U16 can again refer to the importance of years of practise in youth kayaking since greater boat stability comes with experience, and greater boat stability also allows the correct execution of the paddle technique at higher SR.

Sitting height was only significantly correlated with the performance at 200 m in the U14 category. Interestingly, there was a moderate to high negative and significant correlation between the water-shoulder distance in both 200 and 500 m performances, which can be interpreted as an indicator that those who get the fastest times at 200 and 500 m choose to use a higher seat. It is an evidently complex situation, however the results obtained regarding the SH–WSD difference and the SH:WSD ratio seem to corroborate the interpretation of the data. It was verified that the athletes who obtain the fastest times have lower SH:WSD ratios. Which means that when sitting in their boat, the water-shoulder distance tends to approach the sitting height, meaning the differences between their sitting height and water-shoulder distance is smaller, indicating that the seat must be in a higher position.

Even when the SH–WSD difference was lower in kayakers with slower performance times, the SH:WSD ratio was higher, this may be because these athletes had a lower sitting height. This fact may confirm the sitting height as a differentiating characteristic in kayaking and can be interpreted as an indicator that those who get fastest times choose to use a higher seat, having probably the possibility to use longer paddles, and taking from that a mechanical advantage. Moreover, once the higher the seat, the greater the imbalances, due to a higher center of mass in relation to the water, this fact may also suggest that those who perform faster times will possibly have greater technical proficiency, which may result from greater balance and stability. The moderate to high positive and significant correlation observed between the time at 200 and 500 m and the BESS test with foam surface seems to confirm this statement.

Considering the observed data regarding the SH:WSD ratio, it seems possible to speculate a normative value for this indicator that is different for the two categories under study, U14 (1.77 ± 0.02 *n*) and U16 (1.64 ± 0.06 *n*). As for the PL:HGD ratio, the mean value obtained for the s in U14 (3.18 ± 0.28 *n*) and U16 (3.03 ± 0.18 *n*), which are in line with Rademaker, (1977) suggestion that the correct placement of the hands on the shaft should divide the paddle into three equal lengths.

The physical fitness results underline the need to create perfectly adjusted assessment batteries for competition distances and age categories. For example, in the U14, the shuttle run test was significantly and negatively correlated with the 200 and 500 m performance. In turn, in the U16, this significant and negative correlation was verified in pull-ups and sit-ups. Possibly demonstrating a clear difference in strength between the age categories studied, especially if we consider the differences on the values recorded in the handgrip for U14 (27.11 ± 5.43 Kg/f) and U16 (52.86 ± 7.49 Kg/f). Handgrip strength is known to be used as a general indicator of overall muscle strength once Wind et al. (2010) showed a strong correlation between grip strength and total muscle strength. Santos et al. (2011) showed that handgrip strength correlated with the muscle mass indicator at the three maturity levels. A study by Rauch et al. (2002) conducted with 315 children and adolescents (6 to 19 years) showed similarly higher levels of handgrip strength with increasing age, also observed a correlation between strength and stature. Furthermore, isometric strength increases with age in childhood and adolescence; At about 13 years of age, strength development in boys accelerates significantly, and longitudinal data show that adolescent impulses in strength, motor performance, and absolute aerobic power in boys (Beunen & Malina, 2008).

Regarding the paddle's characteristics, an interesting finding is that in the U16 category, the blade width was significantly and positively correlated with time at 200 and 500 m. These data may indicate a clear choice for an oversized blade with evident negative repercussions on the performance, probably because it limits the kayaker's ability to perform high SR and is not compensated with increased SL. This observation seems to be corroborated by the findings of Tsunokawa et al. (2019), indicating a decrease in SR when using hand paddles (which increase the contact surface with water) in swimming. But it differs from the evidence described by Sprigings et al. (2006), which is a study to verify a method for personalising the blade size, indicating that the blade sizes used by the majority of evaluated athletes were close to those predicted by the method. The apparent oversized blade found in the present study may be due because many times in clubs, due to the high price of a new paddle, young athletes are left with old paddles that are no longer suitable for older athletes.

Previous studies have shown that higher SR is associated with better performance in elite adult kayakers (Brown et al., 2011; McDonnell et al., 2013). The present study has similar results for both categories, mainly the U16, with high significant and negative correlations between SR and time to perform the 200 and 500 m, suggesting that increased SR is associated with better performances in youth kayaking, both for 200 and 500 m. More specifically, 119.33 ± 3.51 spm in the 200 m and 100.66 ± 2.30 spm in the 500 m for the U14, and 132.33 ± 2.51 spm in the 200 m and 109.66 ± 2.51 spm in the 500 m for the U16.

The difficulty in recruiting participants to evaluate in minor sports, such as kayaking and canoeing in Portugal and Spain is one of the major limitations of this study. Therefore, despite the promising results, increasing the number of participants in future research's is necessary.

In conclusion, these main findings in the present study suggest the need to produce a specific evaluation battery for U14 that includes, the shuttle run test, and the BESS test, and another for U16 that consists in the evaluation of the pull-up test, and the sit-up test. And the possibility of including in both batteries' information regarding the water-shoulder distance. Suggesting for the SH:WSD ratio, the values 1.77 ± 0.02 *n* for the U14 and 1.64 ± 0.06 *n* for the U16, as being the ones that can contribute to the achievement of better performances.

Another contribution of this work is to highlight the importance of designing training programmes capable of providing young kayakers with the ability to perform the paddle technique with maximum efficiency at high SR. Thus, a correct balance between paddle length, water-shoulder distance, and blade width is essential.

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CHAPTER VII: Study 5

7. Paddle selection and adjustment for young male kayakers: The science behind the art

7.1. Abstract

This study aimed to produce predictive equations to determine the optimal paddle size for young Iberian kayakers competing in three categories, U14, U16, and U18. Data were collected in Portugal and Spain between 2005 and 2018, with a sample that includes 149 kayakers aged 14.42 ± 1.20 years. The kayakers were assessed for somatic maturation using the maturity offset, and the percentage of the predicted adult height (%PAH). For anthropometry, assessing body mass (kg), stretch stature (cm), sitting height (cm), arm span (cm), arm length (cm), forearm length (cm), biacromial diameter (cm) and chest girth (cm), and for equipment setup, measuring paddle and blade length, blade maximum width, handgrip distance. A stepwise multiple linear regression analysis was performed to determine which anthropometric and maturity attributes could predict the paddle configuration for the total sample and each category analysed. Significant differences were found between the three categories for both anthropometry, paddle setup, and maturity, except PAH. Significant differences between U16 and U18 were only found in CA, maturity offset, %PAH, and paddle length. The predictive equation for the total sample explains the variance in paddle length by 75% and may be used as a more objective guide for the paddle scaling.

Keywords: Kayaking; paddle setup; maturity; youth; anthropometry.

7.2. Introduction

The correct optimisation of sporting equipment is vital to achieve maximum performance in competitive sport and to guarantee athlete comfort and injury prevention. However, sport equipment design is often limited not by the natural laws of physics but by the manufactured rules of the sport (Shan, 2008).

Canoeing is a widespread sport worldwide and has been an Olympic event since Berlin in 1936. In sprint kayaking, a defined sequence of cyclical movements is repeated (Kukić et al., 2022), using a double-blade paddle to propel the kayak.

According to the competition rules for canoe sprint of the International Canoe Federation, published in April 2023, the paddles must not be attached to the boat in any way. No other regulations regarding the shape and size of the paddle and its respective blades are suggested. In this discipline, young kayakers use the same materials, often with the same characteristics as adult athletes.

One of the most difficult tasks for coaches is correctly selecting the dimensions of the paddle. The paddle is commonly dimensioned considering the athlete's features (anthropometry, paddling style, technique, strength, etc.), and the most frequently used method, in general, for determining the paddle length is to stand it vertically alongside the kayaker. If the fingers curl over the top blade, the paddle is believed to be about the right size. This method is not ideal and often results in longer than adequate paddles. For determining the correct placement of the hands on the shaft, as a general rule, the most used method suggests that the proper handgrip distances are determined by keeping the shaft of the paddle above the head with the arms horizontal and the forearms vertically forming a right angle with each other, dividing the paddle into three equal lengths (Rademaker, 1977).

Burke & Pruitt (2003) stated that an incorrect equipment adjustment would probably affect the athlete's comfort, ability to perform the technical movement in perfect conditions, and, subsequently, his performance. Taking this as a discriminatory factor in elite categories, we must consider youth categories and the impact this fact may have on the correct learning of the paddle technique and consequently performance.

For example, Timmerman et al. (2015) suggest that correct scaling of net heights and the racquet length or court size may lead to a more attractive learning environment, and Buszard et al. (2016) reported that the scientific evidence suggests scaling as an effective strategy to improve learning and skill performance. Furthermore, with the combination of equipment size and the practitioner's development stage, the skills are performed more successfully and with more desirable movement patterns (Buszard et al., 2014; Farrow & Reid, 2010).

However, there are few normative data on optimising the equipment set-up according to human morphology in sprint kayaking (Diafas et al., 2012; Ong et al., 2006), and even fewer have focused on young kayakers (Alacid et al., 2014). Consequently, athletes and coaches in kayak competitions face various equipment setup decisions that affect performance. Often this process of tuning the equipment set-up requires hours of practise and depends on the subjective feedback of the athlete, driving the approach to a trial-and-error process. However, for many athletes, the equipment is defined more by comfort than any consideration of the mechanical advantage it may provide (Ong et al., 2005).

Thus, with the intent of minimizing the hours of trial and error to find the ideal adjustment of the paddle, this study aimed to produce predictive equations for determining the ideal kayak paddle scaling by evaluating the maturational, anthropometric and current paddle configuration characteristics of young Iberian athletes from three different age categories in competition, U14, U16, and U18.

7.3. Materials and Methods

Participants and data collection

Data were collected in Portugal and Spain between 2005 and 2018, with a sample that includes 149 kayakers aged 14.42 ± 1.20 years, ranging from 12.06 to 16.80 years, and distributed over three competitive categories, U14 (13.15 ± 0.48 years), U16 (15.02 ± 0.59 years) and U18 (16.24 ± 0.21). The sample aggregated kayakers who attended the training camps of the respective national teams and kayakers who did not reach that level. All participants had at least one year of paddling experience and had participated in national competitions. The exclusion criteria were mandatory approval on the required medical exams, non-smokers, and no alcohol consumption habits. Written informed consent from parents or guardians was obtained.

Anthropometry

All measurements were taken following the procedures described by the International Society for the Advancement of Kinanthropometry by an experimented researcher. Body mass (kg) was determined using a SECA 878 (Digital scale, SECA, Germany). Stretch stature (cm) and sitting height (cm) were determined with a SECA 206 (Portable stadiometer, SECA, Germany). Arm span (cm) was measured using a metallic tape (Stanley, USA); the arm length (cm) and forearm length (cm) were measured using a sliding calliper (Siber-Hegner GPM Calliper, Switzerland). The biacromial diameter (cm) was measured using a sliding anthropometer (Siber-Hegner GPM Anthropometer, Switzerland), and the chest girth (cm) was measured using an anthropometric tape (Lufkin W606PM, USA). All instruments were verified and calibrated before the beginning of each testing session to avoid measurement errors. All measurements were taken two or three times, depending on whether the difference between the first two measurements was greater than 1%. The mean or median of the two or three measurements were used, respectively.

Maturity status

Somatic maturation was used to evaluate biological development (Baxter-Jones et al., 2005) by assessing the maturity offset (Mirwald et al., 2002). This method is an indicator of the temporal distribution and proposes to estimate the distance in years, in which the subject is of the peak growth velocity in height (PHV). This value can be negative (if the PHV has not yet been reached) or positive (if the PHV has already been exceeded). Also, the percentage of predicted adult height (PAH%) defined the maturity status, and the athlete-predicted adult height (PAH) was estimated using the method of Sherar et al. (2005) method.

Equipment setup

The paddle setup of the athletes was measured by the same investigator for paddle and blade length and width and handgrip distance (Ong et al., 2005). The paddle length (cm), the horizontal distance between the tips of the blades, was measured using metallic tape (Stanley, USA). Blade length (cm), the horizontal distance between the tip of the blade and the point of the shaft where the structure begins to form the blade, blade width (cm), the maximum width of the blade, and handgrip distance (cm), the horizontal distance between the joints of the third digit with the athlete using the usual grip on the paddle shaft, were measured using a sliding calliper (Siber-Hegner GPM Anthropometer, Switzerland). All measurements were taken twice and the mean of the two measurements was used.

7.4. Statistical analysis

The normality and homogeneity of the variance hypotheses were verified using the Kolmogorov-Smirnov and Levene tests. Descriptive statistics were processed for each of the variables. Group mean comparisons for maturity, anthropometry, and paddle setup were assessed by the Kruskal-Wallis test and post hoc tests with Bonferroni corrections were applied. Spearman's correlation coefficients (r_s) were calculated to examine the correlation between paddle set-up and maturational and anthropometric characteristics. These coefficients were considered as a very high correlation when the value is between 0.9 and 1, a high correlation when between 0.7 and 0.9, a moderate correlation when between 0.5 and 0.7, a low correlation when between 0.3 and 0.5, and a negligible correlation when between 0 and 0.3 (Mukaka, 2012). Additionally, a stepwise multiple linear regression analysis was performed to determine which anthropometric and maturity attributes could predict the configuration of the paddle and blade length, blade width, and handgrip distance for the total sample and each category analysed. All significant variables in the linear correlation, with at least a moderate correlation, were included in the stepwise regression analysis. Predictor variables with variance inflation factor values greater than 10 and/or tolerance levels less than 0.1 were excluded from the model. The level of significance was established at $p < 0.05$. Statistical analyses were performed with SPSS Statistics 27.0 (SPSS Inc., Chicago, IL, USA).

7.5. Results

The mean values for maturity, anthropometry, and paddle setup parameters for the total sample and kayakers grouped by age are presented in Table 7.1. and Table 7.2., respectively.

Only PAH does not correlate significantly with paddle set-up measures in the total sample (Table 7.1). For kayakers grouped by age, significant differences ($p < 0.05$) were observed in CA and all maturity and anthropometric parameters between U14 and U16 and U14 and U18. Between U16 and U18, significant differences ($p < 0.05$) were observed only in CA, maturity offset, PAH% and paddle length (Table 7.2.).

The stepwise linear regression equations are shown in Table 7.3. for the total sample and Table 7.4. for kayakers grouped by age. In the total sample, PAH% and stretch stature significantly contributed to the prediction of paddle length ($p < 0.01$). In U14, paddle length was also significantly predicted by PAH% ($p < 0.01$) and stretch stature ($p < 0.05$), while in U16 it was significantly predicted by maturity offset and %PAH ($p < 0.05$), and in U18 by biacromial diameter ($p < 0.01$).

The predictive equation for the total sample represented 75% of the variance in paddle length. At the same time, the predictive equations for U14, U16, and U18 accounted for 67, 33, and 54%, respectively, for paddle length.

Table 7.1. Mean (± SD) for CA, maturity, anthropometry, paddle set-up, and its correlation (*rs*) with paddle length, blade length, blade width, and handgrip distance for the total sample.

	Kayakers total sample (n= 149)				
	Mean (± SD)	Paddle Length	Blade Length	Blade Width	Handgrip distance
CA (years)	14.42 ± 1.20	0.723**	0.562**	0.575**	0.454**
Maturity					
Maturity Offset (years)	0.98 ± 1.18	0.789**	0.603**	0.614**	0.465**
PAH (cm)	180.19 ± 4.93	0.002	– 0.103	– 0.146	0.019
PAH (%)	94.35 ± 4.30	0.792**	0.600**	0.607**	0.425**
Anthropometry					
Body Mass (kg)	62.04 ± 11.03	0.628**	0.543**	0.567**	0.422**
Stretch Stature (cm)	169.98 ± 8.24	0.712**	0.512**	0.487**	0.457**
Sitting Height (cm)	89.10 ± 4.87	0.691**	0.493**	0.509**	0.420**
Arm Span (cm)	174.18 ± 9.80	0.651**	0.498**	0.438**	0.492**
Arm Length (cm)	31.92 ± 2.45	0.685**	0.436**	0.418**	0.409**
Forearm Length (cm)	25.33 ± 2.21	0.544**	0.264**	0.324**	0.380**
Chest Girth (cm)	89.55 ± 7.65	0.641**	0.550**	0.597**	0.409**
Biacromial Diameter (cm)	37.85 ± 3.64	0.610**	0.596**	0.564**	0.430**
Paddle Set-up					
Paddle Length (cm)	209.27 ± 6.86	–	0.658**	0.627**	0.511**
Blade Length (cm)	47.56 ± 4.25	0.627**	–	0.789**	0.245**
Blade Width (cm)	16.03 ± 3.95	0.658**	0.789**	–	0.204*
Handgrip Distance (cm)	69.73 ± 5.44	0.511**	0.245**	0.204*	–

CA: chronological age; PAH: predicted adult height. *Correlation is significant at the level $p < 0.05$. ** Correlation is significant at the level $p < 0.01$.

Table 7.2. Mean (± SD) for CA, maturity, anthropometry, paddle setup and its correlation (*rs*) with paddle length, blade length, blade width and handgrip distance, for kayakers grouped by age.

	Kayakers grouped by age (n=149) - Mean (± SD)														
	U14 (n=59)	Paddle Length	Blade Length	Blade Width	Handgrip distance	U16 (n=73)	Paddle Length	Blade Length	Blade Width	Handgrip distance	U18 (n=17)	Paddle Length	Blade Length	Blade Width	Handgrip distance
CA (years)	13.15 ± 0.48	0.436**	0.155	0.236	0.411**	15.02 ± 0.59$^{\partial}$	0.342**	– 0.041	– 0.012	0.086	16.24 ± 0.21†§	0.331	0.402	0.187	0.402
Maturity															
Maturity Offset (years)	– 0.17 ± 0.81	0.732**	0.334**	0.380**	0.603**	1.58 ± 0.59$^{\partial}$	0.502**	0.139	0.142	0.002	2.41 ± 0.51†§	0.343	0.296	– 0.067	0.486*
PAH (cm)	181.84 ± 4.45	0.356*	0.106	0.206	0.262*	179.22 ± 5.32$^{\partial}$	0.211	0.078	– 0.094	0.053	178.66 ± 2.97†	0.328	0.013	– 0.029	0.488
PAH (%)	90.03 ± 3.41	0.733**	0.290*	0.372**	0.602**	96.84 ± 1.61$^{\partial}$	0.513**	0.114	0.085	– 0.127	98.62 ± 1.04†§	0.443	0.349	– 0.025	0.419
Anthropometry															
Body Mass (kg)	54.43 ± 9.74	0.687**	0.351**	0.335**	0.528**	66.14 ± 8.55$^{\partial}$	0.222	0.329**	0.367**	– 0.056	70.85 ± 9.00†	0.486*	0.413	0.157	0.629**
Stretch Stature (cm)	163.76 ± 8.01	0.734**	0.314*	0.412**	0.599**	173.55 ± 5.56$^{\partial}$	0.433**	0.182	– 0.001	– 0.011	176.21 ± 3.78†	0.488*	0.280	0.079	0.377
Sitting Height (cm)	85.56 ± 5.02	0.739**	0.351**	0.389**	0.597**	91.22 ± 3.01$^{\partial}$	0.439**	0.124	0.112	– 0.023	92.25 ± 3.16†	0.181	0.125	– 0.136	0.249
Arm Span (cm)	167.02 ± 9.68	0.608**	0.311*	0.325*	0.524**	178.35 ± 6.48$^{\partial}$	0.347**	0.173	– 0.039	0.122	181.13 ± 6.85†	0.624**	0.237	0.103	0.584*
Arm Length (cm)	30.02 ± 2.00	0.602**	0.345**	0.291*	0.362**	33.05 ± 1.85$^{\partial}$	0.432**	– 0.084	– 0.122	0.083	33.65 ± 1.87†	0.492*	0.060	– 0.096	0.291
Forearm Length (cm)	23.67 ± 1.71	0.389**	– 0.054	0.110	0.442**	26.43 ± 1.92$^{\partial}$	0.190	– 0.254*	– 0.146	– 0.013	26.35 ± 1.13†	0.398	0.016	– 0.215	0.308
Chest Girth (cm)	83.20 ± 5.79	0.595**	0.216	0.262*	0.385**	92.82 ± 5.31$^{\partial}$	0.208	0.279*	0.352**	– 0.024	97.58 ± 5.17†	0.197	0.244	0.112	0.455
Biacromial Diameter (cm)	36.14 ± 2.58	0.637**	0.391**	0.340**	0.510**	39.16 ± 1.59$^{\partial}$	0.154	0.323**	0.257*	– 0.089	39.95 ± 2.31†	0.655**	0.458	0.340	0.463
Paddle Set-up															
Paddle Length (cm)	203.95 ± 7.40	–	0.543**	0.549**	0.621**	212.22 ± 3.34$^{\partial}$	–	0.328**	0.170	0.114	215.11 ± 2.52†§	–	0.652**	0.315	0.501*
Blade Length (cm)	46.55 ± 2.22	0.543**	–	0.696**	0.231	48.84 ± 1.46$^{\partial}$	0.328**	–	0.517**	– 0.180	49.48 ± 0.57†	0.652**	–	0.706**	0.310
Blade Width (cm)	15.07 ± 0.63	0.549**	0.696**	–	0.191	15.87 ± 0.53$^{\partial}$	0.170	0.517**	–	– 0.267*	16.19 ± 0.39†	0.315	0.706**	–	– 0.003
Handgrip Distance (cm)	67.09 ± 6.07	0.621**	0.231	0.191	–	70.87 ± 3.90$^{\partial}$	0.114	– 0.180	– 0.267*	–	73.96 ± 4.59†	0.501*	0.310	– 0.003	–

CA: chronological age; PAH: predicted adult height. *Correlation is significant at level $p < 0.05$. ** Correlation is significant at level $p < 0.01$; $^{\partial}$Significant difference ($p < 0.05$) between U14 and U16; †Significant difference ($p < 0.05$) between U14 and U18 and §Significant difference ($p < 0.05$) between U16 and U18.

Table 7.3. Regression equations for the total sample to predict paddle and blade length and blade width for the total sample.

Variable		R^2	SEE (cm)
Paddle Length	Paddle Length= 76.416 + (0.934 × %PAH**) + (0.263 × Stretch Stature**)	0.75	3.43
Blade Length	Blade Length= 20.567 + (0.214 × %PAH**) + (0.191 × Biacromial Diameter*)	0.40	1.63
Blade Width	Blade Width= 6.563 + (0.073 × %PAH**) + (0.024 × Chest Girth*)	0.44	0.53

%PAH: Percentage of predicted adult height.
*Significant contribution ($p < 0.05$) to the predictive model.
**Significant contribution ($p < 0.01$) to the predictive model.

Table 7.4. Regression equations for the categories U14 to predict the paddle length and the handgrip distance, U16 to predict the paddle length, and U18 to predict the paddle length and the handgrip distance.

Variable	U14	R^2	SEE (cm)
Paddle Length	Paddle Length= 55.719 + (0.972 × %PAH**) + (0.371 × Stretch Stature*)	0.67	4.28
Handgrip Distance	Handgrip Distance = – 18.896 + (0.525 × Stretch Stature**)	0.48	4.41
	U16		
Paddle Length	Paddle Length= 150.344 + (1.813 × Maturity Offset*) + (0.609 × %PAH*)	0.33	2.76
	U18		
Paddle Length	Paddle Length= 182.773 + (0.809 × Biacromial Diameter**)	0.54	1.75
Handgrip Distance	Handgrip Distance = 53.718 + (0.286 × Body Mass*)	0.31	3.93

%PAH: Percentage of predicted adult height.
*Significant contribution ($p < 0.05$) to the predictive model.
**Significant contribution ($p < 0.01$) to the predictive model.

7.6. Discussion and implications

This study aimed to produce predictive equations to help determine optimal paddle scaling for kayakers competing in three age categories, U14, U16, and U18. The main contribution of this study was the development of predictive equations for different paddle fittings. Considering the total sample, one equation could explain 75% of the variation in paddle length. Also, when the age categories were analysed separately, the three predictive equations for U14, U16, and U18 accounted for 67, 33, and 54% of the variation in paddle length. Furthermore, the anthropometric characteristics found in this study for U14 and U16 kayakers were similar to previous studies (Fernandes et al., 2021) and seem to move parallel to the paddle setup characteristics of the three evaluated groups. Kayak U18 showed larger anthropometric characteristics than category U16 and U14, and the U16 had larger anthropometric characteristics than U14. The same trend was observed with respect to the paddle, with the larger paddles generally being used by the U18, followed by the U16 and finally by the U14.

Another interesting finding was that the younger the age group, the better the anthropometric and maturity variables were positively correlated with the paddle length. This fact may indicate that anthropometric and maturity characteristics have a greater influence on equipment selection at earlier ages. Suggesting that, as the athlete ages, other factors (i.e., strength, paddling style, technical efficiency, etc.) may condition the choice of paddle setup. This fact appears to align with Cox (1992), who stated that achieving a sprint paddler's maximum possible performance is a long process with the influence of many interrelated factors. For example, improved fitness will probably help improve technique. Although it may be possible to have a good, efficient paddling technique without the physical fitness to sustain it, it is also difficult to have a proper technique with poorly designed or inadequate equipment.

In the present study, the anthropometric characteristics that showed a higher correlation with paddle length were stretch stature and sitting height for the total sample, U14 and U16 ($p < 0.01$), categories, and the biacromial diameter and arm span of U18 ($p < 0.01$). Regarding maturity status, maturity offset and %PAH showed significant correlations ($p < 0.01$) with and paddle length, for the total sample, U14 and U16. In a previous study, Alacid et al. (2014) showed that paddle length correlated strongly with stretch stature and arm span.

In the study of Ong et al. (2005), stretch stature was the anthropometric characteristic most associated with the equipment setup for elite male sprint kayakers serving as a predictor of hand grip distance ($R^2= 0.541$; $p < 0.001$) and foot bar distance ($R^2= 0.589$; $p< 0.001$), these last a variable related to kayak fitting. These authors reported that other regression analyses showed significant relationships between measures of body size and paddle length and blade length. However, only 20% and 25% of the variance of the dependent variables are represented. The authors considered the significant positive relationship between these set-up parameters and height, biacromial breadth, chest girth, arm length, and arm span. Already, Diafas et al. (2012) reported that total arm length, arm span, total leg length , stature ($r= 0.33$, $p < 0.01$), body mass and lean body fat ($r= 0.44$, $p< 0.001$) were significantly correlated with paddle length.

Ong et al. (2006) presented the paddle length as 121.4% of the stretch stature and 118.3% of the arm span in elite kayakers, and Alacid et al. (2014), studying young kayakers, presented it as 121.9 and 118.4% of the stretch stature and arm span, respectively. In the present study, the results were similar, with the paddle length expressing 123.1% of the stretch stature and 120.2% of the arm span with regard to the total sample and 124.5, 122.3, and 122.1% of the stretch stature and 122.1, 118.9, and 118.8% of the arm span for U14, U16, and U18, respectively.

This study is not without limitations. The sample is not homogeneous between the evaluated categories, and the fact that it does not include data on the physical fitness and performance of the athletes can also be limiting. In addition, the possibility of an experimental study is suggested to verify the validity of the predictive equations resulting from this study. Also, an experimental study designed to evaluate the effect of the technique in the selection of equipment, as well as to allow understanding the reliability of the use of predictive models for the selection of paddle set-up for young kayakers. The use of data collected between 2005 and 2018 can also be considered a limitation of this study.

In conclusion, from the several predictive equations developed to help scale the setup of the paddle of the young kayakers, the one that best explains the variation in paddle length is the one developed for the total sample (R^2= 0.75; SEE= 3.43, $p < 0.01$) and goes as follows:

[**Paddle length** = 76.416 + (0.934 × %PAH**) + (0.263 × Stretch Stature**)].

These findings may prove extremely important, since they explain the variance in paddle length in 75% and may be used by coaches and kayakers as a more objective guide for the initial setup of their paddle length, avoiding the empirical traditional method. Furthermore, considering that 25% of the paddle length variation may be due to several other factors, the present information and data can be used to speed up the experimenting process to find the optimal paddle setup that matches the kayaker's size, strength, and technique to achieve better performance.

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CHAPTER VIII: General Discussion

8. General discussion

Excellence is the primary goal of various art forms and also in sports, and so the development of an athlete to achieve maximum performance is a long process, and many factors influence and determine the overall performance, such as technique, physiological characteristics (strength, cardiovascular efficiency, etc.), equipment (cloth, boat, paddle, etc.), personality (emotions and motivation), health status, tactics and strategies (employment by athletes and fellow contestants), diet/nutrition and environmental conditions. Some factors are interrelated, for example, improved fitness can facilitate better technique. However, it may be possible to have an excellent, effective paddle technique without the physical ability to sustain it for a long time. Thus, some factors depend entirely on each other, for example, it is difficult to have a suitable technique with poorly designed or inadequate equipment (Cox, 1992).

Study 1 focused on validating a global positioning system with an accelerometer for canoe/kayak sprint kinematic analysis. Furthermore, study 1 appears as an opportunity since, according to Scott et al. (2016), GPS devices facilitate more objective planning by attempting to optimize future performances. These devices replace the time-consuming and laborious VID methods to quantify the athlete's kinematics in many team sports (Coutts & Duffield, 2010). Furthermore, the significant advantage of using these devices is that they allow to test athletes in actual performance situations. The ICF allows units without real-time information in competition (World Cups, World Championships, and Olympic Games). In fact, since 2017, GPS-Acc units containing a 10 Hz GPS have been used in competition (ST Innovation, Geneva, Switzerland).

The main finding of Study 1 was the agreement between the stroke rate analysis methods regarding all the distance splits (total race, 50 m start, intermediate 100 m splits and 50 m finish). There was also agreement regarding the velocity analysis, except for the start of the race (first 50 m). This analysis took into account a broad spectrum of average velocities (3.20 and 6.65 $m.s^{-1}$) and stroke rates (31 and 168 spm) performed in a canoe sprint competition since it has several boats of one, two and four paddlers on a canoe or kayak.

In opposition to our findings, previous studies in kayaking (Janssen & Sachlikidis, 2010) have reported that GPS data tend to underestimate speed. SR data obtained by the GPS-Acc unit proved not valid for measuring SR (McDonnell et al., 2012), which may be due to differences associated with the technology of the GPS-Acc itself, which was not as advanced in 2010 and 2012 respectively. The validated methodology in Study 1 was then used to collect and analyse performance and kinematics data later in Study 4. To our knowledge, this work was the first to attempt a comparison analysis with both types of vessels in an actual competition situation.

Studies 2 and 3 have focused on the importance of biological maturation and the experience in specific kayaking performance and maturity status, RAE, and the influence of CYE in young Iberian male kayakers, respectively.

In the case of Study 2, although previous canoeing studies have focused on analysing athletes from a morphological and a maturity point of view (Alacid et al., 2015; Alacid et al., 2011; López-Plaza et al., 2017, 2019) and considering performance (López-Plaza et al., 2016), none addressed to the experiences of young kayakers with such emphasis. And even though those studies reported that the most biologically mature paddlers performed the best, they did not consider the influence of years of practise on the observed results. Perhaps, because they evaluated the best athletes in their age groups. In our case, the fact that all athletes were evaluated, from those who performed better to those with less relevant performance, allowed us to understand that more mature athletes perform better effectively. However, at the same time, they have more specific experience in the sport. These data allow us to speculate that maturation issues can be blurred by the years of practise of the young kayakers, particularly in circuit competitions, where decision-making has greater preponderance.

Study 3 focused on the analysis of maturity status, RAE and the influence of CYE in young Iberian male kayakers. The main findings suggest, namely, in the U16 category, the CYE and the maturity status seem to influence the performance. Although it has not been extensively studied in kayaking, to our knowledge, Study 3 is the second study in kayaking that focusses on these topics. The only previous study by Isorna-Folgar et al. (2014) reported that 37.5% of paddlers who participated in the Spanish National Training Camps were born in the 1st BQ; however, those who achieved medals in World Championships or Olympic Games were born in the 4th BQ (35.1%). Interestingly, when analysing the fifteen male Iberian kayakers who participated in the Tokyo Olympics, eleven were born in the third and fourth BQ, five in the third BQ, and six in the fourth BQ. This fact, associated with the need for technical mastery that kayaking imposes, may explain why the RAE may not be observed at the senior elite level.

Likewise, Study 3 showed that the U14 has a higher percentage of births in the 3rd and 4th BQ's. Remarkably, this percentage increases when looking only at the U14 born in 2005. On the other hand, in the U16 total sample, most of the athletes were born in the first two BQ's. It was also found that little more than half of kayakers born in 2003 were born in the first two BQ's. The third BQ was where the highest number of kayakers in the total sample was born.

Considering CYE, in the U14 category, significant differences ($p < 0.05$) were observed between athletes born in 2006 and those born in 2005 for CA, stretch stature, sitting height, maturity offset, and PAH%. Although, these were not only not reflected in significant differences in performance, as the younger kayakers were the ones with better performances. Perhaps because the above-mentioned differences were masked by years of practice, moreover, study 2 already showed that young kayakers usually perform best with more years of specific practise.

Study 4 focused on determining the variables that better explain the performance of young male kayakers at 200 and 500 m in two different categories, U14 and U16, with the aim of creating more suitable evaluation batteries according to age group. Additionally, to identify whether SR is a determinant factor in performance in these categories, such as elite level kayaking (Brown et al., 2011; McDonnell et al., 2013). The main finding of this study was that only water-shoulder distance correlated significantly with performance in both categories in the two distances tested. This is a fact that allows to speculate that the best kayakers choose to use a higher seat, eventually because they have greater stability and balance, and with that, greater capacity to more efficiently produce the high SR required to obtain better performances. A higher seat can also influence the subsequent choice regarding paddle length. This study also reinforces that U14 and U16 kayakers are probably severely affected by kayaking experience and maturity-based differences that influence all other variables. The suggestion of the values 1.77 ± 0.02 n for the U14 and 1.64 ± 0.06 n for the U16 for the SH:WSD ratio, as being the ones that can contribute to the achievement of better performances was also a major contribution of this study, that should be tested and confirm in future studies.

These results align with our findings from Study 1 and previous investigations. Forbes et al. (2009) have reported that age, height, and sitting height were significantly correlated with 1000 m performance. Likewise, López-Plaza et al. (2016) evaluated young kayakers' anthropometric, physical fitness, and specific performance characteristics. They reported significant differences based on maturity for body mass, height, sitting height, overhead medicine ball throw, and specific performance tests at 1000, 500, and 200 m.

Furthermore, the need to create adjusted assessment batteries for the sport seems corroborated by Gäbler et al. (2021), who reported that physical fitness tests show a more significant association with performance when they share similarities in biomechanical and physiological terms. In the case of study 4, the right and left lateral medicine ball throw only correlated significantly with the time at 200 m for the U14 category. In U16, the pull-up test correlated significantly with the time required to perform both distances.

Regarding maturational aspects, study 4 shows that only in the U14 have maturity indicators significantly correlated with performance and only with 200 m, which also may indicate kayaking experience as a levelling factor between kayakers with different maturity levels, which is aligned with our findings in study 2.

Considering SR, it is possible to verify that, according to previous studies in adult athletes and young athletes, a higher SR is effectively correlated with performance. It should be noted that in study 4, when the focus was on the paddle's characteristics, an interesting finding is that in the U16 category, the blade width was significantly and positively correlated with time at 200 and 500 m. These data may indicate a clear choice for an oversized blade with evident negative repercussions on the performance, probably because it limits the kayaker's ability to perform high SR and is not compensated with increased SL. This observation seems to be corroborated by the findings of Tsunokawa et al. (2019), indicating a decrease in SR when using hand paddles (which increase the contact surface with water) in swimming.

Thus, study 4 highlights the importance of designing training programmes capable of providing young kayakers with the ability to perform the paddle technique with maximum efficiency at high SR. Consequently, a correct balance between paddle length, water-shoulder distance, and blade width is essential.

In that regard, Study 5 was designed to produce predictive equations to determine the ideal kayak paddle scaling for three age categories, U14, U16, and U18. It is not a secret that Olympic flatwater kayaking requires a high level of skill to succeed at the international level, and modifications in technique and equipment are made continuously to improve performance (Kendal & Sanders, 1992). Ironically, even today, in a sport that has focused on innovating the design and materials of its boats and paddles, the most frequently used method, in general, for determining the paddle length is to stand it vertically alongside the kayaker. If the fingers curl over the top blade, the paddle is believed to be about the right size. This method is not ideal and often results in paddles that are longer than adequate, thus making the correct selection of paddle dimensions one of the most challenging tasks for coaches and athletes.

The main contribution of Study 5 was the development of predictive equations for different paddle fittings. Considering the total sample, one equation could explain 75% of the variation in paddle length. Also, when the age categories were analysed separately, the three predictive equations for U14, U16, and U18 accounted for 67, 33, and 54% of the variation in paddle length.

Another interesting finding was that the younger the group age, the better the anthropometric and maturity variables were positively correlated with the paddle length. This fact may indicate that anthropometric and maturity characteristics have a greater influence on equipment selection at earlier ages. Suggesting that, as the athlete ages, other factors (i.e. strength, paddling style, technical efficiency, etc.) may condition the choice of paddle setup. This fact appears to align with Cox (1992), who stated that achieving a sprint paddler's maximum possible performance is a long process with the influence of many interrelated factors. For example, improved fitness will probably help improve technique. Although it may be possible to have a good and efficient paddling technique without the physical fitness to maintain it, it is also challenging to have a proper technique with poorly designed or inadequate equipment.

A previous study by Alacid et al. (2014) showed that paddle length strongly correlated with stretch stature and arm span. While in study 5, the anthropometric characteristics that showed a higher correlation with paddle length were stretch stature and sitting height for the total sample, U14 and U16 categories, and the biacromial diameter and arm span for U18.

Diafas et al. (2012) reported that total arm length, arm span, total leg length, stature ($r= 0.33$, $p < 0.01$), body mass, and lean body fat ($r= 0.44$, $p< 0.001$) were significantly correlated with paddle length, and Ong et al. (2006) presented paddle length as 121.4% of the stretch stature and 118.3% of arm span in elite kayakers, and Alacid et al. (2014), studying young kayakers, presented it as 121.9 and 118.4% of the stretch stature and arm span, respectively. In Study 5, the results are similar, with the paddle length expressing 123.1% of the stretch stature and 120.2% of the arm span with regard to the total sample and 124.5, 122.3, and 122.1% of the stretch stature and 122.1, 118.9, and 118.8% of the arm span for U14, U16 and U18, respectively.

These findings may prove extremely important, since they explain the variance in paddle length by 75% and may be used by coaches and kayakers as a more objective guide for the initial setup of their paddle length, avoiding the empirical traditional method.

It is important to underline that this thesis has limitations. Regarding Study 1, reports on data collected in canoe sprint races performed in the northern hemisphere, specifically in the European territory (Portugal), which can influence the number of satellites used for triangulation beyond the impact of the time of the day on the GPS data. Future investigations should use units from other brands to verify the validity of their use in canoe sprint and other territories. In addition, this study uses different VID and GPS-Acc sampling rates to analyse the variables, considering that the available GPS technology is limited to around 15 Hz. Another limitation is the possible video error sources due to the parallax effect. Finally, given the data analysis, the fact that different indexes were considered regarding the start of the race, in the VID, it was the official start, and, in the GPS-Acc unit, it was the boats' movement start, could also have limited the comparison.

Concerning Study 2, the distances analysed were the 3000 and 5000 m, which are performed in a circuit. In-circuit events, athletes can navigate in groups on watercourses with variable width and depth and with the need to go around the buoys several times, thus increasing the probability of a misfortune such as capsizing the vessel, failing the number of laps, shortcut, or increasing the route distance or breaking the rudder. Also, the impossibility of assessing all competition' participants may be considered a limitation. In addition, the specific nature of the competition, ability to ride the opponent's wave, tactical decision-making, problems due to equipment malfunction (paddle and kayak), and the fact that there was a qualifying event on the morning of the competition may all have negatively influenced performance.

In Study 3, a limitation was the assumption of a uniform birth season of broader populations and age sub-groups from different regions. Similarly, despite an effort to evaluate all the U14 and 16 kayakers participating in the competition, the sample size is still limited, so data must be interpreted cautiously. About Study 4, the study's major limitation was the small sample size. Therefore, despite the promising results, increasing the number of participants in future research’s is necessary.

Finally, in Study 5, the sample was not homogeneous between the evaluated categories, and the fact that it does not include data on the physical fitness and performance of the athletes can also be limiting. The use of data collected between 2005 and 2018 can also be considered a study limitation.

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CHAPTER IX: Conclusions

9.1. Implications and transfer of knowledge

Chapter IX aims to summarise in a combined way the contributions of the five studies, presenting the main findings and potential practical applications, trying to reflect on future implications of research and trying to promote a better understanding of the youth Iberian kayakers in the various stages of their maturational and sporting development. It also aims to identify the qualities explanatory of competitive success, whether they relate to maturational, anthropometric, and/or paddle characteristics, adopting a multidisciplinary approach to examine the specificity of performance characteristics in youth kayaking.

Young athletes are exposed to large changes that determine different effects of the training. It is necessary to encounter the specific uniqueness of youth, to increasing the sporting potential, in order to produce success at long-term. There is a need to improve the right research, the standards of training and the development, and hopes of those who can make a difference for youth sports. Encourage healthy coaching, training, and competition practises overall (Bergeron, 2010).

The training programmes must be well-targeted and well planned, after all there are no short cuts. For young athletes, there are mainly two ways in which they can improve their performance: training and growing. Therefore, young athletes are exposed to large changes that determine different effects.

Thus, and according to our perspective and interpretation the results obtained in this thesis, not offering certainties, it offers the following clarifications:

i. GPS-Acc devices can considerably reduce the time analysis demanded by the VID and facilitate the analysis, with quickness and accuracy, of the training sessions, competition velocity, SR, and other variables estimated from these. Although when a more detailed analysis of the paddling technique is required, the use of VID is suggested;
ii. It is essential to focus on the potential of young athletes to develop towards expert performance. And that it seems mandatory the establishing of evaluation batteries that contain information at least on maturity status and years of specific practise, and is specific for each age group;
iii. In Portugal and Spain, U14 and U16 kayakers are subgrouped by year of birth, with the older kayakers categorised as group A and the youngest as group B, and one way of refining this form of distribution of participants

would be to adopt a race classification grouping system similar to the biobanding, as suggested by Cumming et al. (2017);

iv. Training programmes must be designed to provide young kayakers with the ability to perform the paddle technique with maximum efficiency at high SR. For this to happen, it is equally essential to verify a correct balance between paddle length, water-shoulder distance, and blade width;

v. The equations resulting from this Thesis will help to quickly, and easily obtain a setup for the length of the paddle.

9.2. Challenges for future research

One of the significant limitations of scientific research in kayaking, namely in Portugal and Spain, is the difficulty in recruiting participants to evaluate in this type of research projects. A clear limitation of this work is the small sample size, particularly in Study IV. Thus, considering the specific limitations of the five studies addressed in the respective chapters, the options taken during the investigation, and our interpretation of the results, suggests some paths for future research.

Regarding GPS-Acc use, future investigations should use units from other brands to verify the validity of their use in canoe sprint and other territories. In addition, it may be interesting to validate the latest GPS-Accc technology, considering the use of VID with a higher sampling rate (i.e. 60 and 120 fps).

Future studies, more than only focus on anthropometric, maturity, and performance variables, should also consider the possibility of evaluating the technical skills of the athletes and may also consider including motivational and behavioural variables and training environments, such as social context, coach and parental support, coach experience, peer acceptance, enjoyment, quality of the training sessions, and previous training experiences in other sports.

Concerning the equipment, more specifically the paddle set-up, it may be important to include, in future studies, data regarding the physical fitness and performance of the athletes to try to refine the predictive model. Also, we suggest the possibility of an experimental study to verify the validity of the predictive equations resulting from this Thesis and others to evaluate the technique's effect in the paddle set-up selection.

It may also be important to test different boat designs, smaller and lighter, assessing the implications these changes will have on the technique learning process and, consequently, on performance. At the same time, in our opinion, it will be essential to design new competition formats that are more appealing to young kayakers and meet each age group's needs, and not simply copy the competitive system of adult athletes.

The present Thesis provides original material and seeks to be an incentive for further studies while contributing with practical applicability of its findings to coaches in the field. Furthermore, it seems necessary to include contextual information about the quality of training programmes, namely training load, and thus investigate the influence of these aspects in the respective analysis and interpretation of the data.

9.3. Final considerations

The main purpose of this Thesis is to better understand the performance of young canoeists, in the various stages of their maturational and sporting development, clearly identifying the explanatory qualities of their competitive success whether they are related to maturational, anthropometric or equipment aspects. Trying to offer orientation guides for coaches and athletes based on scientific evidence that help decision making, whether in the creation of competitive programs, training, kayakers physical and performance evaluation or in the adequate selection of equipment setup.

Any analysis of training and performance should be approached with care. But when it comes to youth training, the complexity increases, and extra care is needed. More than providing definitive conclusions, this Thesis raised new questions and opened a new and unique way of approaching the performance characteristics of young kayakers. Considering the variation of methods and sampling in the studies presented in this Thesis, it can be concluded that:

a. The high agreement showed between GPS-Acc and VID results suggests the GPS-Acc unit is a valuable and accurate solution to assess time and velocity variables, and in terms of the SR assessment, it could have been even more reliable than the VID due to the high rate of data analysis;
b. The best performances are obtained by more biologically mature kayakers with larger bodies and more years of specific practise in U14 and U16 age categories;
c. CYE and maturity status seem to influence the performance in the U16. Regarding RAE, despite the fact that there were no statistically significant differences found in the total sample of the two categories assessed, a substantial part of the ten best kayakers of each age group were born between January and June and were early maturers;

d. A specific evaluation battery for U14 that should include the SH:WSD ratio considering the value 1.77 ± 0.02 *n* for the achievement of better performances, the shuttle run test, and the BESS test. For U16, the SH:WSD ratio considering the value 1.64 ± 0.06 *n* for the achievement of better performances, the pull-up test and the sit-up test. Furthermore, increased SR is associated with better performance in youth kayaking for 200 and 500 m, mainly U16;
e. For U14, U16, and U18, an equation common to the three age categories could explain 75% of the variation in paddle length. Furthermore, three predictive equations for each age category accounted for 67, 33, and 54% of the variation in paddle length for U14, U16, and U18, respectively.

The studies in this doctoral Thesis reinforce the need to adjust training and competition to the specificity of the age groups for which they are designed. Also, claims the importance of creating guidelines and global norms with reference indicators for technical skills and properly marking performance benchmarks (maximum and minimum) by age group that must be complied with, to avoid early specialisation. It seems obvious that to sustain a successful path to the adult category, it is necessary to provide opportunities to maximise the potential of young kayakers. It is important to recognise that strategies are needed to allow individuals to learn the paddle technique in different SR bands, with appropriate stimuli for higher SR, and with an adequate selection of the paddle set-up to enhance learning and performance. Enabling all young practitioners to participate in competitions where they can experience competitive success should also be a concern. For example, selecting athletes to integrate training groups or primary teams to achieve immediate results (first team) and other training or secondary teams to develop the athletes to obtain the best performances in the medium to long term.

It is suggested the development of competitive classifications, parallel to the official results, based on biobanding classification. Also, considering that the model adopted in both Portugal and Spain, for the development of young athletes, is the Long-Term Athlete Development from Balyi & Hamilton (2004), the development of training programmes and competition that respect growth and maturation are essential. It is important to maximize the training "windows of opportunity" for the development of motor performance, based on a proper training stimulus during appropriate maturational time periods to enhance their future ability to perform with the highest quality in the elite competitive levels.

For this purpose, we have some possible suggestions:

(1) the possibility of assessing all the participants prior to the competitions and at the end of the race produce additional classifications according to their maturity status at the time of the assessment, for example, <85% (U14 Group 1), ≥85% to <90% (U14 Group 2) for the U14 category, <95% (U16 Group 1), and ≥95% (U16 Group 2);

(2) It is suggested, in addition to the usual process of selecting athletes, based solely on their performance and to integrate training groups or "A" teams to achieve immediate performances, the possibility to select kayakers based on potencial and to develop the athletes to obtain the best performances in the medium to long term.

(3) It is also suggested the creation of specific evaluation battery for U14 and U16. The U14 battery must include, the 20-m shuttle run test, and the BESS test and the U16 batery evaluation the pull-up test, and the sit-up test. In both categories batteries' the inclusion of information regarding the water-shoulder distance, with the indication of SH:WSD ratio, with values around 1.77 ± 0.02 *n* for the U14 and 1.64 ± 0.06 *n* for the U16, as being the ones that can contribute to the achievement of better performances;

(4) it is also highlighted the importance of designing training programmes capable of providing young kayakers with the ability to perform the paddle technique with maximum efficiency at high SR. More specifically, stroke rates around 119.33 ± 3.51 spm in the 200 m and 100.66 ± 2.30 spm in the 500 m for the U14, and 132.33 ± 2.51 spm in the 200 m and 109.66 ± 2.51 spm in the 500 m for the U16;

(5) To finalize, the thoughtful use of the predictive equations developed to help scale the setup of the paddle of the young kayakers, especially the equation that explains 75% of the variation in paddle length ($R^2= 0.75$; SEE= 3.43, $p < 0.01$);

Thus, all agents involved in youth canoeing programmes, namely decision makers and coaches, are strongly encouraged to review their talent identification and selection process competitive programmes and respective training methodologies, in accordance with the findings and suggestions of this Thesis.

9.4. References

Bergeron, M. F. (2010). The Young Athlete: Challenges of Growth, Development, and Society. *Current Sports Medicine Reports*, *9*(6), 356–358. https://doi.org/10.1249/JSR.0b013e3181fc70f3

Cumming, S. P., Lloyd, R. S., Oliver, J. L., Eisenmann, J. C., & Malina, R. M. (2017). Bio-banding in Sport: Applications to Competition, Talent Identification, and Strength and Conditioning of Youth Athletes. *Strength & Conditioning Journal*, *39*(2), 34–47. https://doi.org/10.1519/SSC.0000000000000281

Balyi, I. & Hamilton, A. (2004). *Long- Term Athlete Development. Treinability in childhood and adolescence. Windows of opportunity.* Victoria: National Coaching Institute British Columbia & Advanced Training and Performance Ltd.

APPENDIX A: *Curriculum Vitae*

1. PERSONAL AND PROFESSIONAL DATA

1.1. General information

Full name: Rui António de Almeida Duarte Fernandes
National identity card: 12624439
Date of Birth: May 6th, 1984
Place of Birth: Coimbra, Portugal
Institutional address: Faculdade de Ciências do Desporto, Estádio Universitário de Coimbra, Avenida Conímbriga, Pavilhão 3, 3040–248 Coimbra, Portugal.
Residency address: Urbanização Encosta do Sol Lote 1 – Rés do Chão Direito, 3040-354, Coimbra
Mobile Phone: +351 91 26 03 429
Email: ruitas.fernandes@gmail.com

1.2. Biography

Born in Coimbra, after finishing secondary school at Escola Secundária Quinta das Flores (Coimbra) moved to the University of Coimbra where attained the degree of Graduate in Sports Science (2004-2008) with the dissertation, "Comparison of the anaerobic threshold at 4 mmol.l^{-1} in Kayak and Kayak-ergometer". Later obtained the Master degree in Sports Science – Master Course in Youth Sports Training by the University of Coimbra (2011-2013) with the dissertation, "Analysis of the relationships between the anthropometric characteristics of young kayakers, the paddle set-up, and the performance". From 2017 to 2023 was a PhD student in Sport Sciences in the branch of Sports Training (submitted and waiting public defense).

From 2008 to 2013, have worked as sports technician in several sports clubs and entities. Since then, he has been involved with Canoe Sprint as a collaborator of the Portuguese Canoe Federation (2014-2019). Also, as a canoe sprint coach in Clube Fluvial de Coimbra (2015-2019), and Associação Académica de Coimbra (2017-…). He is an invited assistant professor at the University of Coimbra (2017-…), and a canoe sprint Coach at the Portuguese Canoe Federation (2022-…).

1.3. Interests

- ✓ Training
- ✓ Talent identification and development programs
- ✓ Sport expertise

1.4. Academic degrees

- **Period:** 2017-2023 (submitted and awaiting public defense).

Academic degree: PhD in Sport Sciences in the branch of Sports Training
Institution: Faculty of Sport Sciences and Physical Education of the University of Coimbra, Portugal
Title: Sports Specialisation in Young Male Kayakers: Studying the young athlete, sports selection process, performance, and equipment setup
Classification: N.A.

- **Period:** 2011-2013

Academic degree: Master in Youth Sports Training
Institution: Faculty of Sport Sciences and Physical Education of the University of Coimbra, Portugal.
Title: Analysis of the relationships between the anthropometric characteristics of young kayakers, the paddle set-up, and the performance
Classification: 18 on a scale of 0 to 20

- **Period:** 2004-2008

Academic degree: Bachelor in Sports Sciences
Institution: Faculty of Sport Sciences and Physical Education of the University of Coimbra, Portugal.
Classification: 15 on a scale of 0 to 20

1.5. Field-test assessment experience

a) Anthropometry (International Society for the Advancement of Kinanthropometry);
b) Canoe and Kayak Equipment setup evaluation (Ong et al., 2005);
c) Physical Fitness overhead medicine ball throw (Gabbett & Georgieff, 2007); sit-and-reach (Lopez-Miñarro et al., 2013); multistage 20-m shuttle-run test (Léger & Lambert, 1982); pull-up, push-up, and sit-up tests (The Cooper Institute for Aerobics Research, 1999); handgrip strength (Council of Europe, 1988);
d) Postural Stability the Balance Error Scoring System (BESS) (Iverson & Koehle, 2013).
e) Kayaking Performance 1000-m, 500-m and 200-m trials, with or without wireless unit with a 15-Hz GPS and a 3D IMU.

1.6. Network / Main Co-authors

Beatriz Branquinho Gomes: Research Unit in Sport and Physical Activity, Faculty of Sport Sciences and Physical Education, University of Coimbra, Portugal
Fernando Alacid: Faculty of Education Sciences, Health Research Center, University of Almeria, Spain
André Branquino Gomes: Research Unit in Sport and Physical Activity, University of Coimbra, Portugal
Lorena Correas-Gómez: Faculty of Education Sciences, University of Málaga, Spain
Daniel López-Plaza: Sport Medicine Chair, Catholic University of Murcia, Spain

2. SCIENTIFIC RESEARCH

2.1. Chapters in books

a) **Rui Fernandes**, Beatriz Gomes, Ricardo Rebelo-Gonçalves, João P. Duarte, João R. Pereira, A. Cupido-dos-Santos (2013). The anthropometric characteristics of young paddlers and their relationship with paddle set-up and performance. In M. J. Coelho-e-Silva, A. Cupido-dos-Santos, A. J. Figueiredo, J. P. Ferreira & N. Armstrong (Eds), Children and Exercise XXVII: The Proceedings of the 28th Pediatric Work Physiology Meeting, October 2013 (pp.269–272). London; New York: Routledge;

b) João Duarte, Vítor Severino, João Pereira, **Rui Fernandes**, Filipe Simões†, Ricardo Rebelo-Gonçalves, João Valente-dos-Santos, Vasco Vaz, André Seabra, Manuel J Coelho-e-Silva (2013). Reproducibility of Repeated Dribbling Ability. In M. J. Coelho-e-Silva, A. Cupido-dos-Santos, A. J. Figueiredo, J. P. Ferreira & N. Armstrong (Eds), Children and Exercise XXVII: The Proceedings of the 28th Pediatric Work Physiology Meeting, October 2013 (pp. 287–291). London; New York: Routledge;

c) Ricardo Rebelo-Gonçalves, António Figueiredo, Vítor Severino, João Duarte, Filipe Simões†, João Valente-dos-Santos, João Pereira, **Rui Fernandes**, Vasco Vaz, Amândio Cupido-dos-Santos, Manuel J. Coelho-e-Silva, Antonio Tessitore, Neil Armstrong (2013). Agreement between anaerobic peak outputs obtained from the application of common braking force and the estimated optimal load in soccer goalkeepers. In M. J. Coelho-e-Silva, A. Cupido-dos-Santos, A. J. Figueiredo, J. P. Ferreira & N. Armstrong (Eds), Children and Exercise XXVII: The Proceedings of the 28th Pediatric Work Physiology Meeting, October 2013 (pp. 277–281). London; New York: Routledge.

2.2. Articles in peer review international journals

a) **Fernandes, R.A.**, Gomes, B.B., & Alacid, F. (2023). Maturity Status, Relative Age and Constituent Year Effects in Young Iberian Kayakers. Applied Sciences, 13(1), 560. https://doi.org/10.3390/app13010560;

b) **Fernandes, R.A.**, López-Plaza, D., Correas-Gómez, L., Gomes, B.B., & Alacid, F. (2021). The Importance of Biological Maturation and Years of Practice in Kayaking Performance. International Journal of Environmental Research and Public Health, 18(16), 8322. https://doi.org/10.3390/ijerph18168322;

c) **Fernandes, R.A.,** Alacid, F., Gomes, A.B., & Gomes, B.B. (2021). Validation of a global positioning system with accelerometer for canoe/kayak sprint kinematic analysis. Sports Biomechanics, 1–12. https://doi.org/10.1080/14763141.2021.2005128.

2.3. Articles in peer review national journals

a) Ricardo R. Gonçalves, António Figueiredo, **Rui Fernandes**, Filipe Simões, Manuel Coelho e Silva, Antonio Tessitore (2013). Diving technique in young soccer goalkeepers – reproducibility of two new tests. Annals of Research in Sport and Physical Activity, 4, 63-66; dx.doi.org/10.14195/2182-7087_4_7.

b) João P Duarte, Vítor Severino, João R Pereira, **Rui Fernandes**, Filipe Simões, Ricardo Rebelo-Gonçalves, João Valente-dos-Santos, Vasco Vaz, André Seabra, Manuel J Coelho e Silva (2013). Reproducibility of repeated dribbling ability. Annals of Research in Sport and Physical Activity, 4, 51-54; dx.doi.org/10.14195/2182-7087_4_4.

2.4. Abstracts in international conference proceedings

a) Carvalho NC, **Fernandes RA**, Gomes BB, Alacid, F (2022). Ritmo de pagaiada em kayak: estudo exploratório. In F Alacid, M Isorna-Folgar, T. Álvarez-Yates. (Editors). Libro de Actas del VIII Congreso Internacional de Entrenadores de Piragüismo. pp: 15;

b) **Fernandes RA**, Gomes BB (2022). Relative Age Effect: Características de Jovens Kayakistas Ibéricos por Trimestre e Ano de Nascimento. In F Alacid, M Isorna-Folgar, T. Álvarez-Yates. (Editors). Libro de Actas del VIII Congreso Internacional de Entrenadores de Piragüismo. pp: 15;

c) **Fernandes RA**, Gomes BB. (2022). A importância da antropometria em jovens kayakistas: Do desempenho à configuração do equipamento. In F

Alacid. (Editors). Actas del I Congreso Iberoamericano de Antropometría Aplicada. pp: 22;

d) Gomes BB, Quendera I, **Fernandes RA** (2022). Pacing and stroke kinematics in elite paracanoeing racing. European Journal of Adapted Physical Activity 2022, 15, 6; doi: 10.5507/euj.2022.003;

e) Alacid F, Correas-Gómez L, López-Plaza D, Abellán-Aynés O, Manonelles P, **Fernandes RA**, Gomes BB, Martínez-Rodríguez A, Maceroni C, Muyor JM, Isorna-Folgar M (2022). Agreement Between Anthropometric and Ultrasound Based Methods in the Estimation of Biological Maturation in Young Male Athletes. In M Marfell-Jones, F Esparza-Ros, A Adhikari (Editors). Proceedings of the XVII World Conference on Kinanthropometry. pp: 4;

f) Duarte J, Severino V, Pereira JR, **Fernandes RA**, Simões F, Rebelo-Gonçalves R, Valente-dos-Santos J, Vaz V, Seabra A, Coelho-e-Silva MJ (2013). Reproducibility of Repeated Sprint Ability. In M Coelho-e-Silva, A Cupido-dos-Santos, A Figueiredo, J Ferreira, N Armstrong (editors). Book of abstracts of the 28th Pediatric Work Physiology Meeting. Anadia: University of Coimbra pp: 110.

g) **Fernandes, RA.**, Gomes, BB., Rebelo-Gonçalves, R., Duarte, J., Pereira, JR., Santos, A.C. (2013). The anthropometric characteristics of young paddlers and its relationship with the performance in the 1000 meters race. In N Balagué, C Torrents, A Vilanova, J Cadefeau, R Tarragó, E Tsolakidis (editors). Book of abstracts of the 18th annual Congress of the European College of Sport Science. 20)

h) **Fernandes, R.A.**, Gomes, B.B., Rebelo-Gonçalves, R., Duarte, J., Pereira, JR., Santos, A.C. (2013). The anthropometric characteristics of young paddlers and its relationship with the paddle set-up.In M Coelho-e-Silva, A Cupido-dos-Santos, A Figueiredo, J Ferreira, N Armstrong (editors). Book of abstracts of the 28th Pediatric Work Physiology Meeting. Anadia: University of Coimbra.

i) Rebelo-Gonçalves R, Figueiredo AJ, Duarte JP, Pereira JR, **Fernandes RA**, Simões F, Severino V, Valente-dos-Santos J, Cupido-dos-Santos A, Coellho-e-Silva MJ, Tessitore A, Armstrong N (2013). Agreement between peak power outputs obtained from the application of common braking force and the estimated optimal load in soccer goalkeepers. In M Coelho-e-Silva, A Cupido-dos-Santos, A Figueiredo, J Ferreira, N Armstrong (editors). Book of abstracts of the 28th Pediatric Work Physiology Meeting. Anadia: University of Coimbra pp: 107.

3. TRANSFER AND USE OF KNOWLEDGE

3.1. Oral communications

a) XIX Congress of Sport Sciences and Physical Education of Portuguese Speaking Countries, Coimbra, Portugal, 2023;
b) I Iberoamerican Congress of Applied Anthropometry, Almeria, Spain, 2022;
c) VII International Congress of Coaches of Sprint Canoeing 2022, Pontvedra, Spain; Jornadas de Innovación Docente 2020/21, University of Almería, Spain;
d) Canoeing Coaches Forum 2020, Montemor-o-Velho, Portugal;
e) Canoeing Coaches Forum 2019, Montemor-o-Velho, Portugal;
f) 1st Canoeing Coaches Meeting 2018, Esposende, Portugal;
g) VII International Congress of Coaches of Sprint Canoeing 2018, Catoira, Spain;
h) Canoeing Coaches Forum 2018, Montemor-o-Velho, Spain;
i) Canoeing Coaches Forum 2017, Montemor-o-Velho, Spain;
j) XXVIII Pediatric Work Physiology, Anadia 2013;
k) 18th Annual Congress of the European College of Sport Science, Barcelona 2013, Spain; Intensive Program on Sport Performance: A Lifespan Challenge, Rome 2012, Italy.

3.2. Canoeing coach courses

a) Trainer in the Canoeing Coaches Course – Level I (Portuguese Canoe Federation), Portugal, (2014/2015);
b) Trainer in the Canoeing Coaches Course – Level I (International Canoe Federation), Angola, February 2015;
c) Trainer at the Canoe Coaches Course – Level I (International Canoe Federation), Mozambique, October 2014.

3.3. Fieldwork

a) Collaborator of the International Canoe Federation for the International Talent Identification Program (2018);

4. SPORTS EXPERIENCE

4.1. Coaching habilitations

2022: Level 3 Professional License n.º 170395, Portuguese Canoe Federation.

4.2. Coaching positions

a) Portuguese Canoe Federation (FPC) – January of 2022 – (…);
b) University Canoeing National Team – Portugal University Sports (FADU) – 2018 and 2022;
c) University Canoeing Team – Associação Académica de Coimbra (AAC) – April of 2017 – (…);
d) Clube Fluvial de Coimbra (CFC) – August of 2015 – August of 2019;
e) Clube Náutico de Mértola (CNM) – Septembre of 2013 – November of 2013.

5. ACHIEVEMENTS

5.1. Rewards

I. **Best Poster – 2º Place (VIII International Congress of Coaches of Sprint Canoeing 2022);**
II. **Best Poster – 2º Place (VII International Congress of Coaches of Sprint Canoeing 2018);**
III. **Team of the Year 2018 (XI FADU Portugal University Sports Gala)**

5.2. Best sporting results

I. **Canoe Sprint National Team (2022-…)**
  ❖ Juniors & U23 European Championships 2023
  - 2nd Place C1 500 m U23 Women;
  - 4th Place C2 200 m U23 Women;

  ❖ Juniors & U23 World Championships 2022
  - 1st Place C1 200 m U18 Women;
  - 2nd Place C2 500 m U18 Mix;
  - 3rd Place C1 1000 m U18 Women.

  ❖ Juniors & U23 European Championship 2022
  - 3rd Place C1 200 m U18 Women;
  - 2nd Place C1 500 m U18 Women.

II. **University Canoeing Team (AAC) (2017-…)**
  - University National Champions 2023;
  - University National Champions 2022;
  - University National Champions 2021;
  - University National Champions 2019;
  - European University Champions 2018;

- University National Champions 2018;
- University National Champions 2017.

III. National University Canoeing Team, World Championship (2022)

- 1st Place K1 200 m Men;
- 2nd Place K4 200 m Men;
- 2nd Place K4 500 m Men;
- 2nd Place K2 500 m Men;
- 2nd Place K2 200 m Women;
- 3rd Place K2 200 m Women;
- 3rd Place K4 200 m Women;
- 3rd Place C1 200 m Women.

IV. Clube Fluvial de Coimbra (2015-2019)

2019

- 3rd Place K1 200 m U18 Men Portuguese Cup;
- 3rd Place C1 200 m U23 Portuguese Cup;

2018

- 3rd Place K1 200 m U18 Women National Championship;
- 4th Place K2 500 m U18 Women National Championship;
- 4th Place K1 200 m U18 Women Portuguese Cup;
- 1st Place K1 200 mU18 Women B Final;
- 5th Place K4 5000 m Men;
- 6th Place K4 500 m Men;
- 2nd Place C1 1000 m U14 Men National Championship;
- 4th Place C1 3000 m U14 Men in Stage III of the National Championship;
- 3rd place C1 3000 m U14 Men in Stage II of the National Championship;
- 4th Place C1 3000 m U14 National Championship;
- 1st Place C1 3000 m U14 Regional Champion;
- 1st Place C1 1000 m U14 Regional Championship;

2016

- 4th Place K1 500 m U16 Women National Championship;
- 4th Place K1 200 m U16 Women National Championship;
- 3rd Place K4 500 m U18 Women Portuguese Cup.

V. National University Canoeing Team, World Championship (2018)

- 7th Place K2 500 m Men;
- 8th Place K2 1000 m Men;
- 8th Place K4 200 m Men;
- 9th Place K4 500 m Men;

- 9th Place K4 1000 m Men;
- 6th Place K1 500 m Men;
- 9th Place K2 200 m Men.

VI. **Iago Bebiano (2023)**
- 2nd Place K1 200 m Men Portuguese Cup;
- 1st Place K1 200 m Men U23 Portuguese Cup;
- 4th Place K1 500 m Men U23 Portuguese Cup;
- 3th Place K1 500 m Men National Championship;
- 1st Place K1 500 m Men U23 National Championship;
- 2nd Place K1 200 m Men U23 National Championship;
- 2nd Place K2 500 m Men U23 National Championship;
- 7th Place K1 200 m Men World Cup Poznan;
- 5th Place K5 500 m Men U23 European Junior & U23 Championship.

VII. **Mafalda Germano (2023)**
- 2nd Place K1 500 m Women Regional Championship;
- 7th Place K1 200 m Women National Championship;
- 9th Place K1 500 m Women National Championship;
- 8th Place K1 200 m Women Portuguese Cup;
- 9th Place K1 500 m Women Portuguese Cup;
- 3th Place K1 500 m Women Euroregion International Regatta;

VIII. **Rúben Vilas Boas (2023)**
- 1st Place K1 1000 m Euroregion International Regatta Cup;
- 3rd Place K1 500 m Regional Championship;
- 7th Place K1 200 m Men Portuguese Cup;
- 7th Place K1 1000 m Men National Championship;
- 9th Place K1 200 m Men National Championship;

IX. **Rui Lacerda (2018)**
- 2nd Place Marathon European Championship Silver Medal;
- 2nd Place Marathon World Cup (Long Race) Silver Medal;
- 2nd Place Marathon World Cup (Short Race) Silver Medal;
- 9th Place Marathon World Championship (Long Race);
- 9th Place C1 5000 m Men World Championship;
- 1st Place National Championship;
- 2nd Place Marathon National Championship.

X. **Hugo Figueiras (2018)**
- 3rd Place K1 200 m U23 Men Portuguese Cup;
- 1st Place U23 Men SURFSKI World Cup winners.