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Anaerobic Fitness in CrossFit®: assessment, performance prediction and sex differences

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INFORME DE IDONEIDAD DE LA PRESENTACIÓN POR COMPENDIO DE ARTÍCULOS

El Dr. Jerónimo Carmelo García Romero, profesor Titular del Departamento de Fisiología Humana, Histología Humana, Anatomía Patológica y Educación Física y Deportiva de la Universidad de Málaga, como tutor de la tesis doctoral titulada ***"Anaerobic Fitness in CrossFit®: assessment, performance prediction and sex differences"*** presentada por el doctorando D. Tomás Ponce García, informa de la idoneidad de la presentación por compendio de artículos, dado que cumple con todos los criterios establecidos para ello por la Universidad de Málaga. Los trabajos que la componen son los siguientes:

- The Anaerobic Power Assessment in CrossFit® Athletes: An Agreement Study. https://doi.org/10.3390/ijerph18168878

- The association of Whole and Segmental Body Composition and Anaerobic Performance in Crossfit® athletes: sex differences and performance prediction. https://doi.org/10.47197/retos.v62.109115

- Sex differences in anaerobic performance in CrossFit® athletes: a comparison of three different all-out tests. https://doi.org/10.7717/peerj.18930

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En Málaga a 25 de Junio del 2025

“Ad hoc non praedestinatus sum.
Sed fatum meum feci”

“Per aspera ad astra”

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“Cuando bebas agua, recuerda la fuente.”

Proverbio chino

SCIENTIFIC PRODUCTION OF THE THESIS

Journal Article (APPENDIX 1)

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Journal Article (APPENDIX 3)

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ADDITIONAL SCIENTIFIC PRODUCTION OF THE THESIS

Poster presentation at an international congress:

“The Anaerobic Squat Test as a valid and reliable alternative to measure the anaerobic capacity in high intensity functional training athletes “. 25th Annual Congress of the European College Of Sport Science. 28 - 30 October 2020. Online. (Appendix 4)

Poster presentation at an international congress:

“Body composition and anaerobic capacity in High Intensity Functional Training Athletes.” 2021 Annual Meeting & World Congresses of The American College of Sports Medicine. 1- 5 June 2021, Online. (Appendix 5)

Oral presentation at an international congress:

“Relationship between body composition and repeated jump performance in CrossFit® Athletes.” 19th Annual Scientific Conference of Montenegrin Sports Academy “Sport, Physical Activity and Health: Contemporary perspectives". 7-10 April 2022 in Cavtat, Dubrovnik, Croatia. (Appendix 6)

Oral presentation at an international congress:

“Association between Whole Body Phase Angle and anaerobic performance in CrossFit® athletes.” BASES. British Association of Sport and Exercise Sciences. 15-16 November 2022, in Leicester. United Kingdom. (Appendix 7)

Poster presentation at an international congress:

“Intracellular Body Water as a predictor of anaerobic performance in CrossFit® Athletes.” 27th Annual Congress of the European College Of Sport Science. 30 August - 2 September, in Seville. Spain, (Appendix 8)

Poster presentation at an international congress:

“Relación entre el índice de masa libre de grasa (FFMI) y la potencia máxima y media en atletas de CrossFit®.” II Congreso Internacional Sobre Optimización Del Entrenamiento De Fuerza Y Rendimiento Neuromuscular, 6-7 October 2023, in Madrid, Spain, (Appendix 9)

TABLE OF CONTENTS

LISTS OF FIGURES

Introduction

Article 1

Article 2

Article 3

LISTS OF TABLES

Article 1

Article 2

Article 3

ABREVIATIONS

ABT: Assault Bike® anaerobic test

ABTMP: Assault Bike® anaerobic test minimum power

ABTPP: Assault Bike® anaerobic test peak power

ABTXP: Assault Bike® anaerobic test mean power

AMRAP: As Many Rounds/Reps As Possible

AST: Anaerobic squat test

AST60: Anaerobic squat test at 60% of body mass

AST70: Anaerobic squat test at 70% of body mass

ASTMP: Anaerobic squat test minimum power

ASTPP: Anaerobic squat test peak power

ASTXP: Anaerobic squat test mean power

ATP: Adenosine triphosphate

ATP-CP o ATP-PCr: Fhosphagen system

BC: Body composition

BMI: Body mass index

CF: CrossFit®

CMJ: Counter-movement jump

CP: Phosphocreatine

DXA: Dual energy X-ray absorptiometry

FI: Fatigue index

FM: Fat mass

FMP: Fat mass percentage

FT: Fast twitch muscle fibres

HIFT: High intensity functional training

KJ: Kilojoules

LBM: Lean body mass

LELM: Lower extremity lean mass

LEFM: Lower extremity fat mass

LEFMP: Lower extremity fat mass percentage

LM: Lean mass

MP: Minumum power

PCr: Phosphocreatine

PP: Peak power or anaerobic power

RJT: Repeated jump test

RJTMP: Repeated jump test minimum power

RJTPP: Repeated jump test peak power

RJTXP: Repeated jump test mean power

rPP: Peak power relative to body mass

rPP.LM: Peak power relative to lean mass

rPP.MM: Peak power relative to muscle mass

rXP: Mean power relative to body mass

rXP.LM: Mean power relative to lean mass

rXP.MM: Mean power relative to muscle mass

SD: Standard deviation

SEM: Standard error of the mean

SMM: Skeletal muscle mass

ST: Slow twitch muscle fibres

TRFM: Trunk fat mass

TRFMP: Trunk fat mass percentage

TRLM: Trunk lean mass

UELM: Upper extremity lean mass

UEFM: Upper extremity fat mass

UEFMP: Upper extremity fat mass percentage

W: Watts

WBLM: Whole body lean mass

WBFM: Whole body fat mass

WBFMP: Whole body fat mass percentage

WG: Wingate test

WGMP: Wingate test minimum power

WGPP: Wingate test peak power

WGXP: Wingate test mean power

WOD: Workout Of the Day

XP: Mean power or anaerobic capacity

RESUMEN

RESUMEN

Introducción

Aptitud anaeróbica

El rendimiento anaeróbico o aptitud anaeróbica en el deporte se podría definir como la capacidad del deportista de realizar actividades físicas de alta intensidad a través de las vías energéticas anaeróbicas y se refiere a la capacidad de desarrollar una máxima potencia mecánica de pocos segundos de duración, hasta unos 6 segundos aproximadamente, (potencia máxima, potencia pico o también denominada como potencia anaeróbica), así como, la capacidad de mantener altos índices de potencia a lo largo de periodos cortos de tiempo, menos de 60 segundos (potencia media o también denominada como capacidad anaeróbica). El mejor intervalo de tiempo para valorar la aptitud anaeróbica es el de 30 segundos, ya que hasta el 80 % de la energía consumida en un intervalo a máximo esfuerzo de esa duración proviene de fuentes energéticas anaeróbicas. Además, en una prueba más larga, los participantes tienden a no aplicar la máxima intensidad. En intervalos de tiempo de 30 segundos a máximo esfuerzo, el rendimiento depende principalmente de los sistemas energéticos anaeróbicos, que incluyen el sistema de los fosfágenos (ATP-PCr) o anaeróbico aláctico, y la glucólisis anaeróbica o sistema anaeróbico láctico. El sistema de los fosfágenos proporciona energía inmediata pero limitada al utilizar adenosín trifosfato (ATP) almacenado y fosfocreatina (PCr) para la resíntesis rápida de ATP, siendo crucial en esfuerzos de corta duración, como sprints o levantamientos olímpicos. Por otro lado, la glucólisis anaeróbica descompone glucosa o glucógeno sin la necesidad de oxígeno, generando ATP a mayor velocidad, pero acompañado de la producción de lactato, lo que puede contribuir a la fatiga muscular. Estos sistemas son esenciales en actividades que requieren explosividad, potencia y velocidad en intervalos cortos, generalmente de 10 segundos a 2 minutos de duración.

Las principales variables determinantes del rendimiento anaeróbico son la potencia y la capacidad anaeróbica. La potencia anaeróbica (PP), también llamada potencia pico o potencia máxima. Se refiere a la potencia mecánica máxima que un individuo puede generar en un periodo de tiempo específico. Como norma general, en un ejercicio o test de máximo esfuerzo, un levantamiento de peso o un sprint, se produce en los primeros segundos, menos de 10. La energía aportada para este componente del rendimiento anaeróbico proviene predominantemente del sistema de la PCr y ATP. Por lo que podemos decir que depende mayoritariamente del sistema anaeróbico aláctico. La PP depende de factores cuantitativos y cualitativos. La masa muscular activa durante todo el test es el principal factor cuantitativo que limita el máximo desarrollo de potencia. Los principales factores cualitativos probablemente sean el porcentaje de fibras rápidas (FT), eficiencia mecánica y control del motor.

La capacidad anaeróbica, también llamada potencia media (XP). Representa la potencia mecánica promedio generada durante un esfuerzo de alta intensidad. Esta variable expresa la capacidad de un atleta para mantener niveles elevados de potencia durante un periodo más largo, involucrando principalmente el sistema energético anaeróbico láctico. Es un indicador de la resistencia anaeróbica máxima y resistencia muscular y es crucial en deportes que exigen esfuerzos repetidos de alta intensidad, como carreras de media distancia, remo o deportes de equipo como el fútbol y el rugby.

Valoración de la aptitud anaeróbica

Para evaluar la aptitud anaeróbica existen varias pruebas de laboratorio. Sin embargo, la mayoría son caras y difíciles de realizar debido al equipo específico que requieren. Por esa razón, una de las pruebas de laboratorio más utilizadas para evaluar esta capacidad es la prueba de Wingate (WG), que consiste en pedalear con los brazos o las piernas al máximo esfuerzo durante 30 segundos contra una resistencia determinada por el peso corporal del participante. La prueba de WG ha demostrado ser fiable, con una correlación test-retest en muchas poblaciones que oscila entre 0,89 y 0,98.

Aunque el test WG es fiable para la valoración de los atletas, no todos los profesionales del deporte tienen acceso a laboratorios. Para ello, se han creado diferentes pruebas de campo como alternativa válida y asequible. Los tests de campo, que suelen ser elaborados para facilitar la medida de estas capacidades a entrenadores y especialistas del deporte que no tienen acceso a laboratorios de medicina del deporte, así como, para crear herramientas de medida de la aptitud anaeróbica en entornos más familiares para los atletas o con gestos más habituales para estos. Se han elaborado tests de campo basados en distintos gestos deportivos como la carrera, el salto, la sentadilla y otros gestos deportivos específicos. Aunque los tests de campo son una alternativa asequible y accesible para la valoración de los deportistas, es importante elegir pruebas que imiten los gestos realizados por los atletas en sus disciplinas con el objetivo de poder obtener una mejor explicación de los factores que intervienen en el rendimiento de cada tipo de atleta en función de su deporte especifico. La aptitud anaeróbica ha demostrado ser determinante en el rendimiento deportivo en deportes con predominio de esfuerzos de alta intensidad.

CrossFit®

Entre los deportes caracterizados por su alta intensidad, destaca un método de entrenamiento funcional de alta intensidad registrado como CrossFit® (CF). Creado por Greg Glassman en el año 2000, este programa se basa en el desarrollo de todas las capacidades físicas a través de movimientos funcionales constantemente variados y realizados a una intensidad alta. Combina ejercicios de distintas disciplinas, como la halterofilia, la gimnasia, así como ejercicios de acondicionamiento físico (carrera, saltos, remo, etc.). Su objetivo principal es mejorar la capacidad de trabajo en diferentes dominios de tiempo y modalidad, promoviendo una mejora en el estado físico integral a través del desarrollo de las diez capacidades físicas del fitness: 1) resistencia cardiovascular/respiratoria, 2) resistencia muscular, 3) fuerza, 4) flexibilidad, 5) potencia, 6) velocidad, 7) coordinación, 8) agilidad, 9) equilibrio y 10) precisión. Se considera uno de los métodos de entrenamiento de mayor crecimiento en los últimos años y se ha convertido en un deporte de gran interés y participación mundial. Es una disciplina que en los últimos años ha ganado mucha atención en la comunidad científica debido a su popularidad e incremento exponencial de sus practicantes.

Los entrenamientos del día o piezas de entrenamiento son llamados comúnmente WODs (de Wourkout Of the Day) y se clasifican en distintos tipos entre las que destacan las siguientes: “For Time” y “AMRAP”. En los WODs “For Time” los atletas deben completar una tarea prescrita en el menor tiempo posible mientras que en un WOD tipo “AMRAP” los atletas deben completar la máxima tarea posible en un intervalo de tiempo preestablecido. Estos tipos de WODs son utilizados tanto en las sesiones diarias de entrenamiento como en las competiciones a modo de tests de rendimiento de los participantes. Asimismo, los eventos o tests de rendimiento en las competiciones no son anunciados previamente por lo que los atletas deben estar preparados para lo desconocido e impredecible. Esta naturaleza de variabilidad e imprevisibilidad refleja las exigencias a las que están sometidos los practicantes de esta disciplina y los desafíos a los que deben enfrentarse los competidores de este deporte.

La multimodalidad de este deporte (la amplia variedad de ejercicios de los que se compone), conjuntamente a sus características tan especiales (el desconocimiento previo de los eventos de competición) dificultan la capacidad de determinar con precisión los predictores del rendimiento en sus atletas, ya que el éxito puede estar vinculado a la aptitud en una amplia gama de atributos fisiológicos, psicológicos, etc. Además, resulta difícil establecer cuáles son los tests más acertados para valorar el rendimiento en estos atletas.

Actualmente, existe un notable desacuerdo en los métodos utilizados para valorar el rendimiento en atletas de CF, así como en las variables analizadas. Asimismo, no se ha encontrado en la literatura ningún estudio comparativo o de concordancia que evalúe la validez de distintos tests de rendimiento anaeróbico en estos atletas que pueda aportar información de la existencia de una prueba que muestre una mayor precisión en el análisis de la aptitud anaeróbica en este deporte.

Predictores de la aptitud anaeróbica

La importancia demostrada de la aptitud anaeróbica tanto en deportes de equipo como individuales hace que la determinación del perfil anaeróbico en deportistas sea una tarea significativa de los profesionales e investigadores del deporte y ciencias del ejercicio. Además del análisis del perfil anaeróbico, la identificación de los factores predictores de dichas variables de rendimiento puede resultar de gran utilidad para la valoración puntual de los atletas, monitorización a lo largo de la temporada o en el diseño de programas de entrenamiento específicos.

Como predictores de la aptitud anaeróbica, se han identificado diversos factores fisiológicos, morfológicos y psicológicos. Entre los factores fisiológicos se encuentran el volumen muscular del cuádriceps, el ángulo de penación del vasto lateral, el porcentaje de fibras musculares FT, el área de FT y la relación entre el área de FT y el área ST (fibras lentas) en el cuádriceps. Entre los factores morfológicos destacan el somatotipo, la masa corporal, la masa libre de grasa (LBM) y masa muscular (MM). Algunas variables psicológicas, como las habilidades sociales (otra subescala de la escala EI) y el control (una subescala de la escala de fortaleza mental), mostraron una fuerte correlación positiva con el rendimiento anaeróbico. Otros factores, como el agua intracelular o el ángulo de fase han sido asociados a los valores de potencia y/o capacidad anaeróbica.

Predictores del rendimiento deportivo

Además de la asociación entre los distintos factores identificados como predictores y las variables de la aptitud anaeróbica medidas en pruebas de laboratorio y campo específicas, es importante conocer los factores que están asociados con el rendimiento en pruebas deportivas reales.

Algunos autores han asociado las variables obtenidas en los tests anaeróbicos con el rendimiento en distintos deportes. Por ejemplo, se ha asociado la PP registrada con la prueba WG con el rendimiento en patinaje de velocidad y la PP medida a través del salto con contra-movimiento (CMJ) con el rendimiento en el levantamiento de pesas olímpico (arrancada y dos tiempos) tanto en atletas masculinos como femeninos.

Asimismo, en CF, la PP medida con el WG ha demostrado estar relacionada con el rendimiento en algunas de las pruebas como el CrossFit® Total, las puntuaciones de algunos WODs y puntuación final de los CrossFit® Open de 2019, así como en un WOD tipo AMRAP . En la misma línea, la PP medida a través del salto vertical también ha mostrado estar asociado al rendimiento en CF, ya que todas las variables relacionadas con el salto se asociaron en gran medida con al menos cuatro de los cinco WODs y la clasificación final de los Open de 2019. La XP medida con el WG mostró ser buena predictora del rendimiento en patinadores de velocidad, así como en atletas de CF.

La composición corporal (BC) total o segmentaria se utiliza como método de selección, seguimiento a lo largo del año y predicción del rendimiento de los deportistas. La BC ha demostrado que puede afectar significativamente el rendimiento deportivo al influir en la fuerza, la potencia y la agilidad de un atleta. Algunos autores han estudiado la relación entre algunos de los componentes del BC y el rendimiento en diferentes pruebas físicas en deportistas . Por eso mismo, la BC se ha clasificado como factor predictor y está estrechamente relacionada con el rendimiento deportivo de diversas disciplinas deportivas.

Por ejemplo, se ha demostrado que el exceso de masa grasa (FM) tiene un impacto negativo en el rendimiento físico. Por el contrario, se ha demostrado que la LBM está directamente relacionada con el rendimiento deportivo. Una LMB más alta se asocia con una mayor fuerza muscular y un mayor desarrollo de potencia, lo que puede mejorar el rendimiento en deportes que requieren fuerza explosiva, como el levantamiento de pesas, el fútbol, el hockey o el waterpolo. En la misma línea, un trabajo realizado en corredores de esquí de fondo encontró una correlación significativa entre las variables de la LBM y el rendimiento en los sprints, tanto en hombres como en mujeres y solo en mujeres en carreras de distancia. Por lo tanto, niveles más altos de LBM se asocian con un mejor rendimiento anaeróbico en deportistas de múltiples disciplinas.

En CF, varios autores han intentado determinar los predictores del rendimiento en algunos WODs oficiales. Sin embargo, la significativa heterogeneidad en las variables de BC y rendimiento investigadas dificulta la formulación de conclusiones definitivas y apropiadas. La mayor cantidad de LBM y menor FM observada en atletas de CF de mayor nivel puede sugerir la importancia de estos valores en los atletas de este deporte.

Por lo tanto, la identificación precisa de las variables predictoras del rendimiento, así como el desarrollo de modelos de predicción a partir de ellas podría facilitar notablemente la labor a los profesionales encargados del rendimiento en este deporte. Además, las ecuaciones de predicción son herramientas útiles y de bajo coste para estimar el rendimiento de los atletas sin tener que someterles a pruebas de máximo esfuerzo.

Diferencias entre sexos

El sexo biológico se ha identificado como un factor influyente en las diferencias de rendimiento encontradas entre sexos. Estas diferencias son atribuidas a ciertas diferencias anatómicas y fisiológicas entre hombres y mujeres en varios sistemas corporales que determinan los beneficios o los límites del rendimiento físico tanto en personas sanas como enfermas.

Las principales diferencias fisiológicas entre sexos en el rendimiento deportivo se atribuyen a la exposición a niveles altos de testosterona endógena en los hombres durante la pubertad, hasta 15 veces mayor que en mujeres. Esta hormona aumenta la masa muscular, el tamaño de las fibras musculares, la concentración de hemoglobina y el desarrollo general de fuerza y resistencia en los hombres, mientras que permanece baja en las mujeres. Estas diferencias aportan una amplia ventaja a los hombres en las actividades que dependen de la fuerza muscular, la potencia, la velocidad y la capacidad aeróbica.

Además del tamaño de las fibras musculares, existen diferencias en el área proporcional del tipo de fibra. Las diferencias en la distribución del tipo de fibra muscular pueden contribuir a las diferencias de fuerza, ya que las fibras ST ocupan un área mayor en las mujeres y las FT en los hombres. Esto podría explicar por qué las mujeres pueden tener una mayor resistencia a la fatiga en determinadas tareas de resistencia, así como, una menor fuerza que los hombres, siendo de un del 50 al 60% de la fuerza masculina en la parte superior del cuerpo y de un 60 al 70% en el tren inferior.

Algunos autores han sugerido a las diferencias metabólicas y en la utilización del sustrato como factores explicativos de algunas de las diferencias en el rendimiento y la fatigabilidad de los músculos de las extremidades, aunque estas diferencias tienen un impacto menor en el rendimiento absoluto de los atletas de élite. En atletas de élite, aunque las aportaciones de las vías aeróbicas y anaeróbicas han mostrado ser similares entre hombres y mujeres, si se han encontrado diferencias significativas en el gasto energético total.

Otros autores han mostrado las diferencias morfológicas entre sexos en distintas poblaciones. Varios estudios han encontrado diferencias significativas entre hombres y mujeres de diferentes deportes en cuanto a la LBM. En general, los hombres muestran una cantidad de LBM mayor que las mujeres.

Varios estudios han demostrado que existen diferencias significativas en el rendimiento anaeróbico entre hombres y mujeres valorado en distintas pruebas como la de WG, salto vertical , pruebas específicas en piscina y levantamientos de peso como la sentadilla trasera, el peso muerto y el press de banca. En todos los tests, los valores de potencia absolutos fueron mayores en hombres lo que indica una diferencia constante entre sexos en el desarrollo máximo de fuerza en distintos entornos.

Además de los valores absolutos, algunos autores han encontrado diferencias significativas en los valores relativos a la masa corporal, en practicantes de snowboard y de artes marciales. Sin embargo, cuando los valores son ajustados a la LBM, las diferencias dejan de ser significativas en algunas pruebas lo que sugiere que el rendimiento anaeróbico puede estar determinado en mayor parte por la cantidad de LBM.

En practicantes de CF, no se han encontrado estudios que analicen las diferencias entre sexos en el rendimiento anaeróbico en diferentes pruebas de laboratorio o campo de máximo esfuerzo y compararen dichas diferencias en valores absolutos y relativos de masa corporal, LBM y MM durante dichas pruebas.

Los objetivos de esta tesis fueron los de valorar el rendimiento anaeróbico en distintas pruebas de campo basadas en distintos gestos (cicloergómetro, saltos repetidos, bicicleta de asalto y sentadilla) y analizar su concordancia con la prueba de referencia de laboratorio. Determinar la asociación entre los valores de composición corporal total y segmentaria y rendimiento anaeróbico de estos atletas medido en la prueba de WG y desarrollar ecuaciones de predicción que expliquen los valores de potencia y capacidad anaeróbica. Y, por último, realizar una comparación entre sexos de las variables de rendimiento en valores absolutos y relativos a la masa corporal, masa libre de grasa y masa muscular.

Material y Métodos

Artículo 1:

Diecinueve participantes de CF se ofrecieron como voluntarios para participar en este estudio. Eran atletas experimentados que seguían el mismo programa de entrenamiento de los competidores y habían competido en alguna competición nacional o internacional. Excepto por los períodos de descanso establecidos antes de cada prueba, los atletas siguieron su régimen de entrenamiento regular durante esas semanas. Los participantes fueron reclutados y evaluados en un centro local de CF. Todos los participantes dieron su consentimiento informado por escrito. Como criterio de inclusión, se estableció un mínimo de un año de práctica de CF. Se excluyó a cualquier participante con presencia o sospecha de cualquier patología cardíaca, que sufriera o hubiera sufrido recientemente cualquier lesión musculoesquelética o cualquier otra condición que impidiera hacer ejercicio adecuadamente.

Se realizó un estudio transversal durante cuatro semanas con diecinueve voluntarios con más de un año de experiencia, donde se realizaron cinco pruebas anaeróbicas de 30 segundos a máximo esfuerzo, cuatro de campo y una de laboratorio. Dos con sentadilla al (AST60 y AST70), una de saltos repetidos (RJT), una en bici de asalto (ABT) y la de referencia de laboratorio en cicloergómetro (WG). Cada prueba comenzaba con 5 minutos de calentamiento, Seguidamente se estableció otro intervalo de 5 minutos para descanso y preparación de los dispositivos de medida. Posteriormente, se ejecutaba la prueba de máximo esfuerzo. Y, finalmente se pedía al atleta que realizara la actividad suave correspondiente en cada tests para la vuelta a la calma. Los atletas fueron motivados verbalmente por el investigador durante los 30 segundos para que mantuviesen el máximo esfuerzo a lo largo de toda prueba.

Para realizar los análisis estadísticos, se utilizaron la versión 21 del Paquete Estadístico para las Ciencias Sociales (SPSS) y la versión 18.6 del software estadístico MedCalc, MedCalc. El nivel de significación se estableció en $p \leq 0,05$. La normalidad de los datos se comprobó mediante la prueba de Shapiro-Wilks. El análisis de concordancia de las potencias máximas de los cuatro métodos se realizó mediante el análisis de Bland-Altman y el error proporcional se evaluó con la Tau Kendall. Anteriormente, se determinaron las variables de diferencia y media para cada par. Además, se comprobó la significación estadística ($p < 0,05$) de las diferencias entre PP, XP, potencia mínima (MP) e índice de fatiga (IF) de los cinco métodos mediante un análisis de varianza (ANOVA) de medidas repetidas. Cuando se encontró una diferencia significativa, se utilizaron pruebas t de dos colas pareadas post-hoc para determinar qué valores eran significativamente diferentes. Se aplicó el ajuste de Bonferroni para mantener el nivel de significación general en 0,05. La suposición de esfericidad se probó mediante la prueba de Mauchly. Además, el tamaño del efecto por pares se calculó mediante la d de Cohen utilizando el software G*Power 3.1.9.6.

Artículo 2:

Cincuenta atletas de CF de varios centros locales fueron reclutados para participar en el presente estudio, 25 hombres y 25 mujeres. Todos los participantes aceptaron voluntariamente participar tras responder a un anuncio publicado en estos centros. El principal criterio de inclusión fue un mínimo de un año de práctica de CF. Se excluyó del estudio a las personas con lesiones musculoesqueléticas recientes o afecciones médicas que pudieran dificultar su capacidad para realizar la prueba de esfuerzo máximo, como problemas cardíacos. Se aconsejó a los participantes que se abstuvieran de realizar actividades físicas extenuantes en las 24 horas previas a la prueba de esfuerzo. Todos los procedimientos se llevaron a cabo de acuerdo con los principios establecidos en la Declaración de Helsinki y recibieron la aprobación previa del comité de ética de la Universidad de Málaga. Los participantes fueron informados de los procedimientos de antemano y dieron su consentimiento por escrito.

Se realizó un estudio transversal durante 4 semanas. Los participantes fueron sometidos a un análisis de la composición corporal mediante absorciometría de rayos X de energía dual y a una prueba de laboratorio a máximo esfuerzo en cicloergómetro (WG) para determinar su rendimiento anaeróbico. Para el análisis de BC se indicó a los atletas que acudieran al laboratorio en ayunas, sin haber consumido ningún tipo de alimento o bebida durante al menos 4 horas, alcohol en las últimas 24 horas o diuréticos en la semana previa.

A partir de los datos proporcionados por el software del sistema, se extrajeron las variables de masa libre de grasa total (WBLM), masa grasa total (WBFM) y porcentaje de grasa corporal (WBFMP). Se utilizaron los valores del tronco, las extremidades superiores y las extremidades inferiores para la composición corporal segmentaria. Se sumaron los valores absolutos o el promedio de los porcentajes de las extremidades derecha e izquierda para las extremidades superiores e inferiores. Los valores de la cabeza se excluyeron del análisis segmentario. Las variables finales de la composición corporal segmentaria utilizadas fueron: masa magra del tronco en kg (TRLM), masa grasa del tronco en kg (TRFM), porcentaje de masa grasa del tronco (TRFMP), masa magra de las extremidades superiores en kg (UELM), masa grasa de las extremidades superiores en kg (UEFM), porcentaje de grasa de las extremidades superiores (UEFMP), masa magra de las extremidades inferiores en kg (LELM), masa grasa de las extremidades inferiores en kg (LEFM), y porcentaje de grasa en las extremidades inferiores (LEFMP). Todos los valores calculados en gramos por el software fueron convertidos a kilogramos.

El rendimiento anaeróbico se valoró mediante la prueba de WG con una resistencia de 0,075 kp por kg de masa corporal. Se eligió esta prueba porque se ha demostrado que tiene una relación significativa con el rendimiento en varios eventos oficiales de CF. La prueba se realizó con un cicloergómetro Monark 894E. Para determinar la potencia máxima (WGPP), media (WGXP) y mínima (WGMP), se registraron los valores de potencia cada 5 segundos. Durante la primera sesión del estudio se llevó a cabo una primera prueba de familiarización.

Para los análisis estadísticos se utilizaron el paquete estadístico SPSS 26 y el software estadístico MedCalc 18.6. Se calcularon estadísticas descriptivas (media y desviación estándar) para todas las variables. La normalidad se evaluó mediante la prueba de Shapiro-Wilk. Dado que algunas variables no cumplían el supuesto de normalidad, las relaciones entre todas las variables independientes y el rendimiento anaeróbico se cuantificaron calculando los coeficientes de correlación Rho de Spearman. Se realizaron pruebas t de muestras independientes para evaluar las diferencias entre atletas masculinos y femeninos. Los tamaños del efecto para las comparaciones de sexo se calcularon utilizando la d (d) de Cohen. El nivel de significación estadística para todas las pruebas se estableció en p <0,05. Por último, se realizaron análisis de regresión múltiple por pasos para determinar la relación entre las variables independientes y dependientes y crear modelos que explicaran la varianza de las variables de rendimiento anaeróbico. Se realizó un análisis de regresión lineal múltiple por pasos para cada variable dependiente (WGPP, WGXP y WGMP) utilizando datos de composición corporal total o segmentaria. Las variables significativas seleccionadas por el software estadístico se utilizaron para crear un modelo predictivo de las variables de rendimiento.

Artículo 3:

Se realizó un estudio transversal durante dos semanas. Los participantes se sometieron a tres sesiones de evaluación del rendimiento y a una sesión de evaluación de la BC en el laboratorio. En la primera sesión, se sometieron a un análisis de la BC, y en las sesiones posteriores, se sometieron a una prueba de esfuerzo máximo. Todas las sesiones estuvieron separadas por 48 horas.

Cincuenta atletas, 25 hombres y 25 mujeres fueron reclutados para participar. Fueron reclutados a partir de un anuncio distribuido entre los propietarios de centros de CF en Málaga y alrededores. Los criterios de inclusión fueron que los participantes debían entrenar al menos 3 h por semana y que llevaban practicando CF al menos 1 año. Todos los participantes fueron informados de los procedimientos y dieron su consentimiento informado por escrito. Los procedimientos en el presente estudio siguieron las normas de la Declaración de Helsinki y fueron aprobados por el comité de ética de la Universidad de Málaga.

Se realizó a los participantes un análisis de la BC mediante DXA y bioimpedancia eléctrica mediante un InBody 770. La LBM y la MM en kilogramos se extrajeron de las variables de BC. Se incluyó la MM como variable aislada medida por bioimpedancia eléctrica. Su inclusión tenía como objetivo comparar si los resultados obtenidos exclusivamente sobre la

MM, la parte fisiológicamente activa aislada de la LBM (excluyendo huesos y vísceras), mostraban alguna diferencia en comparación con los calculados en base a la LBM.

Para evaluar el rendimiento anaeróbico, se realizaron tres pruebas de esfuerzo máximo de 30 segundos: una prueba de cicloergómetro (WG), una prueba de saltos repetidos (RJT) y una prueba de sentadillas (AST). Se determinaron los valores absolutos de potencia máxima (PP), media (XP) y mínima (MP) para todas las pruebas. Se calculó el índice de fatiga (FI), obtenido a partir del porcentaje de pérdida de potencia a lo largo de la prueba, mediante la fórmula: $FI (\%) = (PP - MP)/PP * 100$. Además, los valores relativos se calcularon dividiendo los valores absolutos por kilogramos de masa corporal (rPP y rXP), LBM (rPP.LM y rXP.LM) o MM (rPP.MM y rXP.MM). Se pidió a los participantes que se abstuvieran de realizar actividades físicas extenuantes 24 horas antes de las pruebas de esfuerzo máximo. Las pruebas se asignaron al azar para evitar sesgos de secuenciación.

Se utilizó el software SPSS versión 21.0 (IBM Corp., Armonk, NY, EE. UU.) para realizar los diferentes análisis estadísticos. La normalidad de las variables se analizó mediante la prueba de Shapiro-Wilk, y la homogeneidad de las varianzas mediante la prueba de Levene. Se realizó una transformación logarítmica para aquellas variables que no cumplían con algunos de los supuestos anteriores (TRFM y WBFM en hombres). Se utilizó la prueba t de Student para comparar los valores medios de los grupos. La medida del tamaño del efecto para las diferencias de sexo se determinó utilizando la d de Cohen calculando la diferencia de medias entre los dos sexos y dividiendo el resultado por la desviación estándar conjunta. El nivel de significación se estableció en $p < 0,05$. Además, las diferencias entre hombres y mujeres se calcularon como porcentajes mediante la siguiente fórmula: $\%\text{-dif} = (MV - FV)/MV * 100$, donde MV corresponde a los valores masculinos y FV a los valores femeninos. Los valores porcentuales positivos significan mayores en los hombres y los valores porcentuales negativos significan mayores en las mujeres.

Resultados

Artículo 1:

El análisis de concordancia de Bland-Altman mostró un error sistemático con una variación en las medias de las diferencias de entre −110,05 vatios (AST60PP−WGPP) y 463,58 vatios (ABTPP−WGPP). A pesar del error sistemático los resultados mostraron una buena concordancia entre todos los métodos (p > 0,05). El análisis de correlación de rangos de Tau Kendall mostró un error proporcional en ABTPP (p < 0,001). Debido a la menor variabilidad intra-sujeto, los resultados sugieren que el AST70 es una prueba de campo válida para evaluar la potencia y la capacidad anaeróbica en atletas de CF.

Artículo 2:

Los resultados mostraron una correlación significativa entre los valores de BC y el rendimiento desde moderada (r = -0,34, p = 0,015) a casi perfecta (r = 0,96, p < 0,01). Además, los modelos de predicción desarrollados mostraron capacidades predictivas que oscilaron entre el 19% y el 93%. Todos los modelos se crearon utilizando las variables de masa libre de grasa total o segmentaria. Se encontraron diferencias significativas entre hombres y mujeres en las variables de BC y rendimiento estudiadas.

Artículo 3:

Se encontraron diferencias significativas entre sexos en todas las variables de potencia máxima y media absolutas y relativas a la masa corporal. En los valores relativos a la masa libre de grasa, solo la potencia máxima de WG mostró diferencias significativas, mientras que RJT y AST no lo hicieron. Las potencias medias relativas a la masa libre de grasa si mostraron diferencias significativas en todos los tests. Sin embargo, en los valores ajustados a la masa muscular, solo mostró diferencias significativas la potencia máxima de WG y la potencia media de AST. En el índice de fatiga, solo se encontraron diferencias significativas en RJT. Los hombres mostraron un 6,2% más de fatiga en el WG que las mujeres. Sin embargo, las mujeres mostraron valores mayores de fatiga en RJT y AST, 17,5% y 17,2%, respectivamente. Estos datos sugieren que la fatiga podría depender de las demandas específicas de la tarea.

Conclusiones

Artículo 1:

Los resultados muestran un buen nivel de concordancia entre los cuatro métodos y WG, siendo mayor en AST70. Sin embargo, debido al error sistemático, no pueden usarse indistintamente. Asimismo, el error proporcional encontrado en ABT podría hacer dudoso su uso. Además, los resultados del presente estudio sugieren que la magnitud de los valores de potencia máxima parece depender del tipo de ejercicio y de las características del atleta.

Artículo 2:

Los resultados demuestran que las variables de BC son indicadores cruciales del rendimiento anaeróbico en atletas de CF. Los atletas con mayor masa libre de grasa y menor grasa corporal muestran un mayor rendimiento en la prueba estudiada. Además, el uso de ecuaciones de predicción podría resultar útil como herramienta para estimar los valores de potencia máxima y media. Esta información podría ser de utilidad para los profesionales del deporte a la hora de monitorizar a los atletas y/o diseñar programas de entrenamiento.

Artículo 3:

Los resultados indican que existen diferencias significativas entre sexos en las potencias máxima y media absoluta y la mayoría de las relativas. Además, sugiere que la cantidad de masa magra y masa muscular, explican la producción de potencia tanto en las pruebas de campo como la de laboratorio. La reducción de dichas diferencias en los valores relativos a la masa magra y muscular sugiere que el rendimiento anaeróbico depende en mayor medida de la cantidad de masa muscular que del sexo. A partir de esto, el diseño de programas de entrenamiento para aumentar la masa muscular podría ayudar en la mejora del rendimiento anaeróbico, especialmente en las atletas femeninas.

I. INTRODUCTION

“No discoveries would be made if we were content with what we know.”

Seneca.

1.1. CROSSFIT®

Definition and characteristics

CrossFit® (CF) is a training programme combining exercises from different disciplines, such as weightlifting, gymnastics, and conditioning (running, jumping, rowing, etc.). Created by Greg Glassman in 2000, this programme is based on developing general physical fitness through constantly varied functional movements performed at high intensity. It is also referred to in the scientific literature as HIFT or high-intensity functional training (Feito et al., 2018) and classified as a functional fitness training method (Dominski et al., 2022). Its main objective is to improve work capacity in different time and modality domains, promoting an improvement in overall physical fitness through the development of the ten physical fitness capacities: 1) cardiovascular/respiratory endurance, 2) stamina, 3) strength, 4) flexibility, 5) power, 6) speed, 7) coordination, 8) agility, 9) balance and 10) accuracy (*CrossFit | "What Is Fitness?" Part 1: 10 Physical Skills*, n.d.). It is considered one of the fastest-growing training methods in recent years (Claudino et al., 2018) and has become a sport of great interest and participation worldwide (Sauvé et al., 2024).

Workouts of the day or bouts of training are commonly called WODs and are classified into different types, among which the following stand out: FOR TIME and AMRAP. A 'For Time' WOD is a piece of training classified as a task-priority WOD. In it, a task is prescribed and must be completed as fast as possible, for example, the famous WOD called "Fran" where athletes must complete a schemed reps of 21-15-9 of thruster and pull up (21 repetitions of each exercise followed by 15 repetitions of each exercise and finished with 9 repetitions of each exercise) in the shortest time possible. The "thruster" exercise is a popular exercise in CF that refers to a front squat continued by a shoulder press without interruption.

In contrast, the AMRAP type WOD, which comes from the abbreviation "As Many Rounds/Reps As Possible", is classified as a time-priority WOD. In it, the athlete must perform as much work as possible in a set time frame. For example, we can name another famous CF WOD called "Cindy", which consists of performing the maximum rounds and repetitions in 20 minutes of 5 pull-ups, 10 push-ups, and 15 air squats.

These training piece formats are used in daily training sessions and competitions as performance tests for participants. Competition events are not pre-announced, so athletes must be prepared for the unknown and unpredictable (Meier et al., 2023; Peña et al., 2021). This variability and unpredictability reflect the demands placed on the practitioners of this discipline and the challenges faced by competitors in this sport (Meier et al., 2023).

On the other hand, the sport's multimodality and very special characteristics make it difficult to accurately determine predictors of performance in its athletes, as success can be linked to a wide range of physiological, psychological, and other attributes.

At present, due to the heterogeneity of the research methods used and the diversity of variables studied, there is no agreement on which are the main predictors of performance (Meier et al., 2023) and which performance tests, both laboratory and field, should be used to evaluate these athletes. Therefore, this should be considered a priority objective for research on this sport.

1.2. SPORTS PERFORMANCE

Sports performance is the capacity of the athlete to execute efficiently and effectively the tasks required by his discipline and under the specific conditions of the competition. This performance is determined by technical-tactical, morphological (anthropometric, body composition, etc), physiological (genetic predisposition, aerobic and anaerobic capacity and power, etc.), psychological (mood, concentration, motivation, stress management, etc.) and sociological (social environment, family support, access to sports equipment, etc.) characteristics of the athletes and the multidimensional interaction between them (Furrer et al., 2023; Jekauc et al., 2023; Nabilpour et al., 2023; Phillips & Hopkins, 2020; Van Der Zwaard et al., 2018; Zambom-Ferraresi et al., 2018). Figure 1 shows schematically the intrinsic and extrinsic determinants of performance. These factors acquire a greater or lesser weight depending on the type of sports activity. Consequently, the identification of these determinants of performance in each sports discipline is a crucial task for sports professionals.

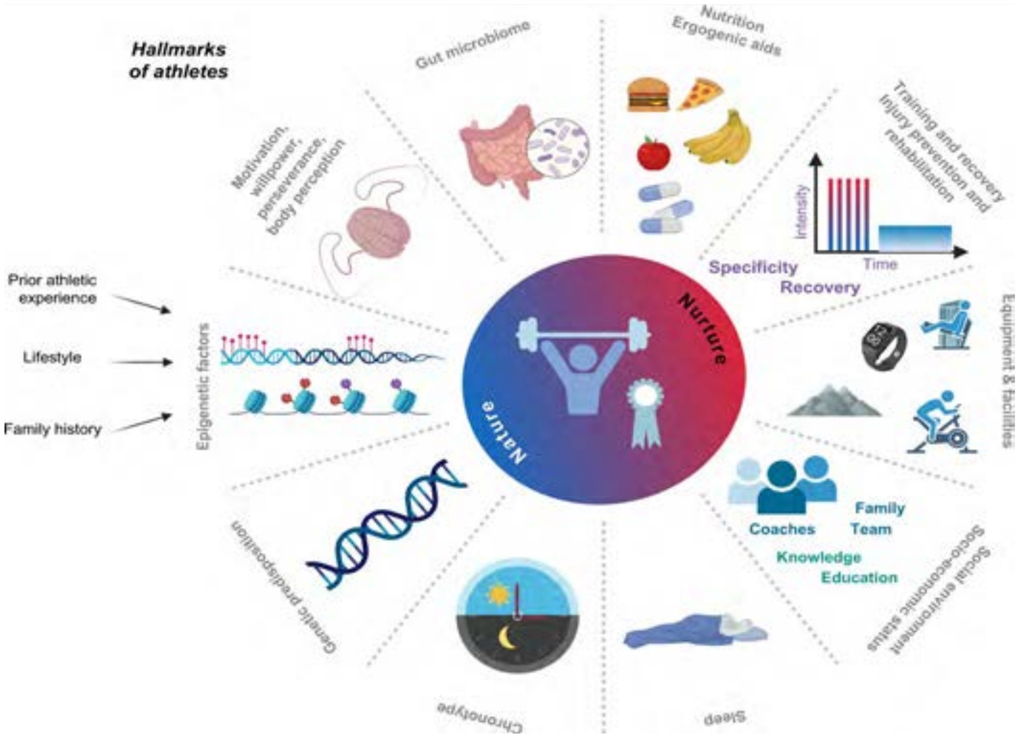


Figure 1. Diagram of the main determinants of sports performance according to Furrer et al. (2023)

Among the most studied capacities in athletes are aerobic and anaerobic performance. Nonetheless, there is controversy about using the terms anaerobic and aerobic because there is no total split between the two systems. However, instead, the obtaining of energy for the execution of a specific exercise or effort is obtained from an energy continuum where all energy pathways are activated at the same time, function simultaneously and interact with each other, contributing to a greater or lesser degree depending on the duration and intensity of the exercise or specific effort (Chamari & Padulo, 2015; Gastin, 2001; Spriet, 2022). Therefore, it would be more appropriate to consider every effort as anaerobic or aerobic predominant. Figure 2 shows the overlap between the energy pathways and how they function simultaneously during exercise. Figure 3 shows the energy contribution of the different systems in a Wingate (WG) 30-second maximal effort anaerobic test.

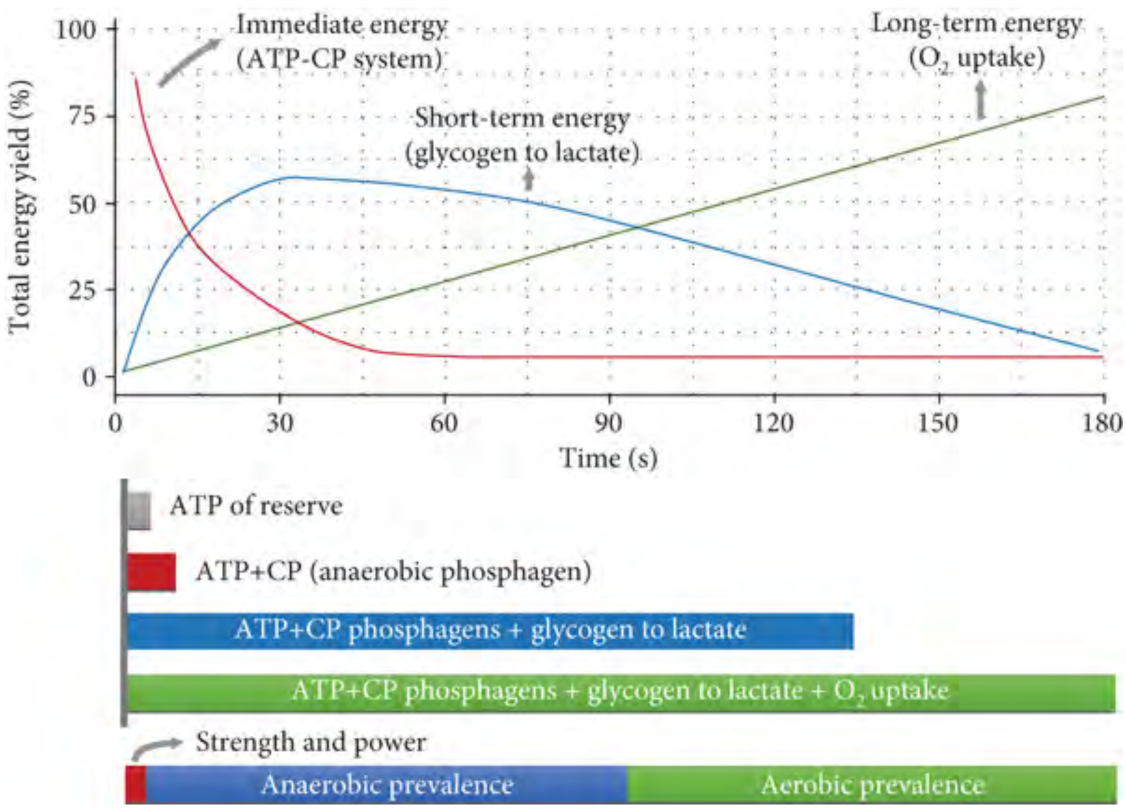


Figure 2. Illustration of the interaction of aerobic and anaerobic energy systems during exercise. From Huertas et al. (2019)

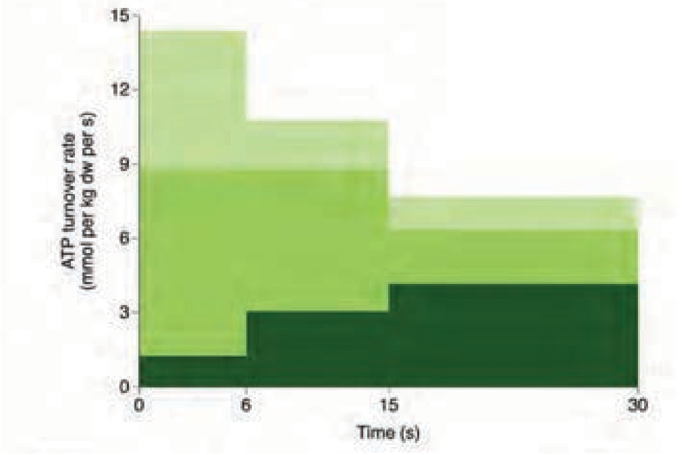


Figure 3. ATP turnover of energy systems during the WG test. PCr system (light green), glycolysis (medium green) and oxidative phosphorylation (dark green). From Hargreaves & Spriet (2020)

1.3. ANAEROBIC FITNESS

The anaerobic performance or anaerobic fitness in sports could be defined as the athlete's ability to perform high-intensity physical activities through anaerobic energy pathways (Green, 1994; Inbar, 2008) and refers to the ability to develop maximum mechanical power for a few seconds duration, up to approximately 6 seconds, (peak power or also referred to as anaerobic power), as well as, the ability to maintain high rates of power over short periods, less than 60 seconds (mean power or also referred to as anaerobic capacity) (Inbar, 2008). The best time interval to measure anaerobic performance is 30 seconds (Green, 1995), as up to 80% of the energy consumed in this time range is produced by anaerobic sources (Beneke et al., 2002; Smith & Hill, 1991). Also, in longer intervals, participants tend not to work at maximum effort (Dal Pupo et al., 2014). Therefore, peak (PP) and mean power (XP) are direct indicators of their anaerobic performance.

In time intervals of 30 seconds at maximal effort, performance depends primarily on anaerobic energy systems, which include the phosphagen (ATP-PCr) or alactic anaerobic system and anaerobic glycolysis or lactic anaerobic system. The phosphagen system provides immediate but limited energy by using stored adenosine triphosphate (ATP) and phosphocreatine (PCr) for rapid ATP resynthesis, being crucial in short-duration efforts such as sprints or weightlifting. The metabolic processes of ATP resynthesis through this system are depicted in Figure 4.

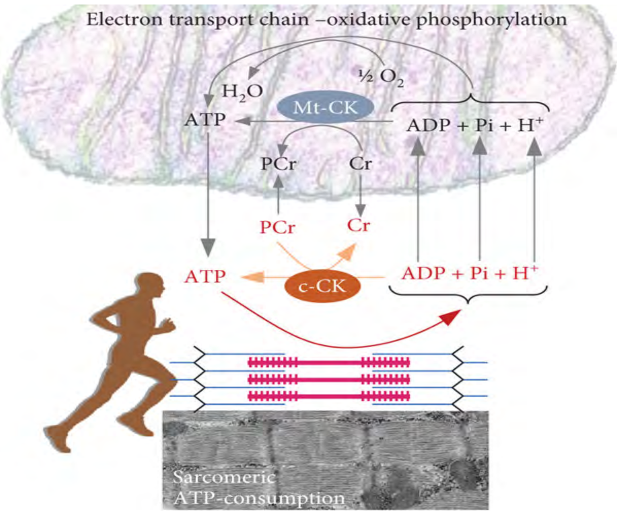


Figure 4. ATP resynthesis processes through the anaerobic ATP-PCr energy system during exercise. From Huertas et al. (2019)

On the other hand, anaerobic glycolysis breaks down glucose or glycogen without the need for oxygen, generating ATP at a faster rate. However, it is accompanied by lactate production, which can contribute to muscle fatigue. These systems are essential in activities that require explosiveness, power, and speed in short intervals, usually 10 seconds to 2 minutes in duration (Serresse et al., 1988; Spriet, 2022). Figure 5 shows a schematic diagram of anaerobic energy production in skeletal muscle.

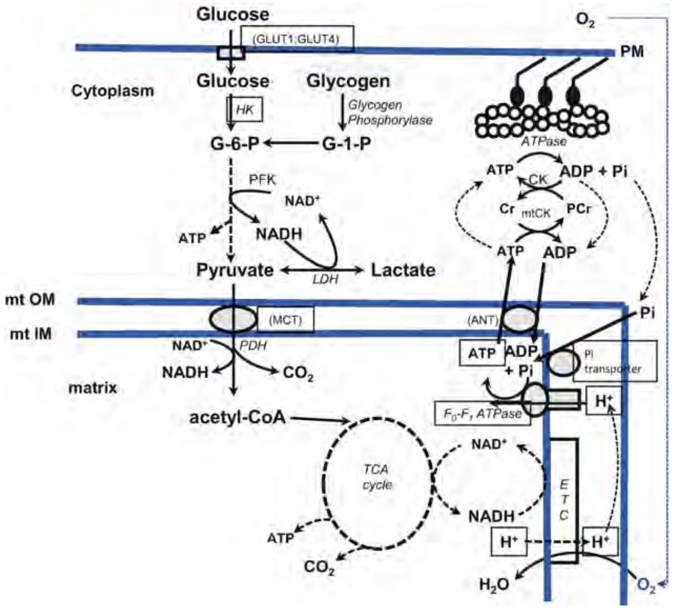


Figure 5. Schematic of metabolic processes through anaerobic pathways in skeletal muscle during exercise. From Spriet (2022)

In contrast, the aerobic system contributes the least in these short, high-intensity efforts. Its energy contribution increases in the last seconds of the test, especially in the last 10 seconds (Smith & Hill, 1991), and it can increase exponentially in efforts longer than 30 seconds (Serresse et al., 1988). Figure 6 plots the contributions of each energy system to the total power output values at each of the 5-second intervals during the WG test.

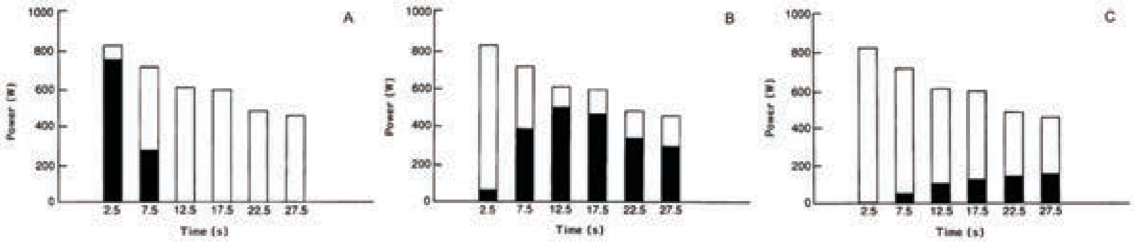


Figure 6. Contribution of each energy system superimposed to the total power outputs for each 5-second interval. A: ATP-PCr system (W), B: Glycolytic system (W) and C: Aerobic system (W). From Smith & Hill (1991)

Anaerobic power (PP)

It is also called peak power or maximum power. It refers to an individual's maximum mechanical power output at a specific time. Usually, in a maximal effort exercise or test, like a weight lift or sprint, it is produced in the first few seconds, less than 10 seconds. The energy contribution comes predominantly from the PCr and ATP systems (Smith & Hill, 1991), so it depends mainly on the alactic anaerobic system.

PP depends on quantitative and qualitative factors. The main quantitative factor limiting maximal power development is active muscle mass throughout the test. The main qualitative factors are likely to be the percentage of fast fibres (FT), mechanical efficiency and motor control (Driss & Vandewalle, 2013). Figure 7 shows a time plot of the power values recorded every second during a WG test.

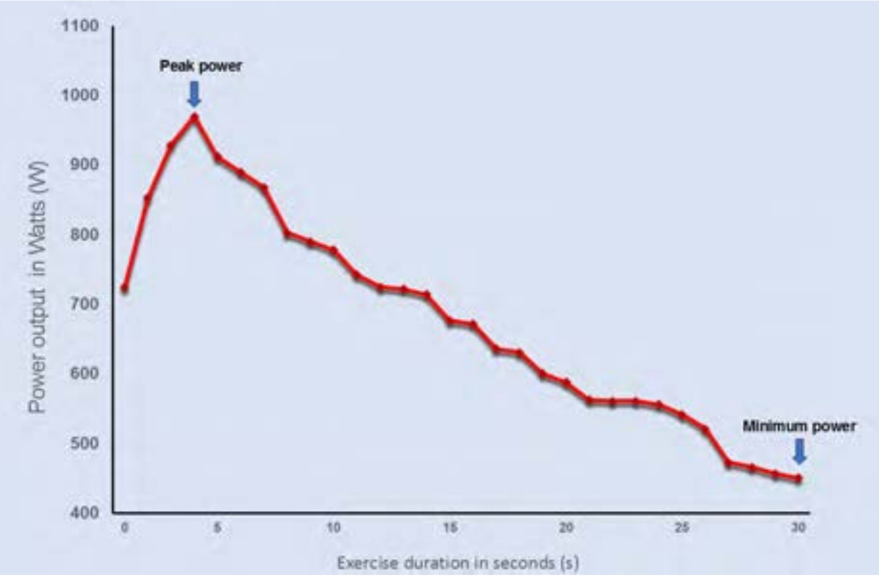


Figure 7. Graphical representation of the power output values recorded in a 30-second WG test at maximum effort where PP and the minimum power (MP) are detailed.

Anaerobic Capacity (XP)

It is also called mean power. It represents the average mechanical power output developed during high-intensity effort. This variable represents the ability of an athlete to maintain high levels of power over a more extended period, mainly involving the lactic anaerobic energy system. It is an indicator of maximal anaerobic endurance and maximal muscular endurance (Inbar, 2008), and it is important in sports that require repeated high-intensity efforts, such as middle-distance running, rowing, or team sports like football and rugby.

1.4. ANAEROBIC FITNESS ASSESSMENT

Understanding the role anaerobic fitness plays in certain sports, it can be essential to assess each athlete's anaerobic profile and how it is associated with performance in their specific sport or playing position. Knowledge of the anaerobic profile can provide valuable information for developing discipline and/or position-specific training strategies.

Numerous tests have been developed to assess anaerobic fitness and determine athletes' profiles, both in the controlled environment of a laboratory and in sport-specific settings. Laboratory tests have been shown to have good reliability and accuracy; however, field tests are gaining popularity due to their advantage of being designed to simulate the specific sporting gestures of each discipline.

Laboratory-based tests

The most widely used anaerobic laboratory test is the WG, which is recognised as the gold standard test for this type of assessment. It is a 30-second maximal effort cycle ergometer test that measures PP, XP and fatigue index (FI) (Bar-Or, 1987). It is considered the most reliable and valid test to assess anaerobic performance in various sports (Bar-Or, 1987; Popadic Gacesa et al., 2009; Theophilos et al., 2016). Moreover, in CF, this test has proven to be highly predictive of competitive performance in several studies (Meier et al., 2023).

Field-based tests

Field tests are a more affordable alternative to laboratory tests. They are often designed to facilitate the measurement of these capacities for coaches and sports specialists who do not have access to sports medicine laboratories and to develop tools to measure anaerobic fitness in environments more familiar to athletes or with sport-specific gestures more common to them.

Tests based on sporting gestures such as running (Andrade et al., 2015; Queiroga et al., 2013), jumping (Čular et al., 2018; Dal Pupo et al., 2014), squatting (Luebbers & Fry, 2015) and other sport-specific gestures (Alves et al., 2015; Theophilos et al., 2016) have been developed.

Although field tests are an affordable and accessible alternative for assessing athletes, it is essential to choose tests that mimic the gestures performed by athletes in their disciplines to better explain the factors involved in each type of athlete's performance according to their specific sport (Boucher et al., 2017).

CF is a high-intensity multimodal sport that requires athletes to excel in a variety of physical capacities, including anaerobic performance. Its multimodality makes it challenging to choose between different performance tests, so it is necessary to determine the best alternatives for assessing and monitoring these athletes throughout the season. No studies have been found on the agreement between different anaerobic tests in these athletes in which the reliability and validity of these tests have been determined.

1.5. ANAEROBIC FITNESS PROFILE IN INDIVIDUAL AND TEAM SPORTS

The study of athletes' anaerobic profiles reveals how important it can be in certain individual and team sports. PP and XP values can vary depending on the specific sport, the athletes' fitness level, or the players' playing position in the same sport.

A study of 145 elite athletes from different disciplines showed that the highest absolute and relative to body mass (rPP) PP values were observed in volleyball and basketball players. These values were significantly higher than those of boxers, wrestlers, handball, and football players. Mean power followed a relatively similar pattern to peak power, with the highest values recorded in sports generally associated with short, high-intensity bursts. The similarity between PP and XP across sports implies that the overall anaerobic capacity is consistently high in disciplines that rely on bursts of power (Popadic Gacesa et al., 2009).

A study of football players (R. E. Mangine et al., 1990) revealed that the elite players had a higher rPP output. This high performance highlights the importance of anaerobic fitness in these elite athletes, enabling them to produce rapid bursts of energy during the game. The variability in power output among the players suggests differences in individual conditioning and specialised roles within the team. Indicating that the rapid bursts of energy required in soccer might be dependent on the player's position.

Another study conducted on judo players (Kim et al., 2011) showed that national team judoists exhibited significantly higher absolute values for anaerobic power compared to junior and university teams. Specifically, national and university teams had greater PP and XP compared to junior teams, indicating that higher performance levels are associated with superior anaerobic fitness. Since the anaerobic system is essential for rapid, powerful actions as those needed to execute judo techniques during bouts, anaerobic fitness is crucial because judoists only have short intervals of activity (around 30 seconds with breaks) during a match. This reliance on quick and powerful movements to win points makes having high anaerobic PP and XP a definite advantage in competitions in judo elite athletes.

In snowboarders, higher values were observed in elite-level athletes compared to their lower-level counterparts. Additionally, within the athlete group, men had higher PP and rPP, as well as rXP, compared to women. These findings emphasise the importance of anaerobic performance, which appears to be crucial in snowboarding events, given their short duration (between 10 to 30 seconds) and high-intensity bursts of activity requirements (Zebrowska et al., 2012).

These results suggest that anaerobic performance is key to high team and individual sports performance.

In CF, the anaerobic profile has been studied by numerous authors to determine the relationship between these variables and actual performance in competition.

A comparative study between elite CF athletes and elite alpinists revealed higher anaerobic performance in both male and female CF practitioners. These findings suggest that

CF athletes have a better ability to generate power quickly over short periods. In addition, although both sports require high levels of power, CF athletes are particularly well-prepared for short-term, maximum-intensity efforts (Sauvé et al., 2024).

Another study found a positive relationship between WG PP and a higher number of repetitions in an AMRAP but not in a “For Time” style WOD. However, “For Time” WOD-type performance was more tightly linked to athlete experience. The results of this study indicate that different CF WOD styles place varying demands on athletes (Bellar et al., 2015).

Martínez-Gómez et al. (2020) found that WG rPP and rXP were significantly correlated with performance in multiple WODs, highlighting that power relative to body mass is a critical component. In addition, markers of vertical jumping ability (including SJ, countermovement jump (CMJ), and reactive strength index (RSI)) showed large and very large correlations with the number of repetitions in most WODs.

Additionally, in a published review paper, back squat maximal strength, among other variables, was classified as a predictor of CF performance (Meier et al., 2023).

All the above-mentioned results suggest that, as in other sports, anaerobic performance is important in higher-level CF athletes.

1.6. ANAEROBIC FITNESS PREDICTORS

PP and XP have been associated with various physiological, morphological, and psychological factors, which are considered predictors of anaerobic performance.

Among the physiological predictors are those shown by Kordi et al. (2020) in their study of elite cyclists. The results showed that quadriceps femoris muscle volume and vastus lateralis pennation angle are important predictors of PP. They were higher in sprint cyclists.

Another study by Bar-Or et al. (1980) concluded that there is a positive relationship between the percentage of FT muscle fibres, FT area and the ratio of FT area to ST area (slow fibres) in the quadriceps and PP, as assessed by the WG test.

Morphological predictors of anaerobic performance include somatotype (Ryan-Stewart et al., 2018), body mass (Popadic Gacesa et al., 2009), lean body mass (LBM) (Kim et al., 2011; Vardar et al., 2007; Zera et al., 2022) and muscle mass (MM) (Kim et al., 2011).

Some psychological variables, such as social skills (another subscale of the EI scale) and control (a subscale of the mental toughness scale), showed a strong positive correlation with anaerobic performance (Nabilpour et al., 2023).

Other factors, such as intracellular wáter (Otremba et al., 2024) or phase angle (Martins et al., 2021), have been associated with power and/or anaerobic capacity values.

1.7. SPORT PERFORMANCE PREDICTORS

In addition to identifying predictors of PP and XP through field or laboratory testing, it is important to analyse factors associated with athletes' performance in a competitive or simulated competitive environment. Obtaining data on variables related to faster running times or better match results can make the difference between success and failure in competition. This approach can improve the accuracy of predictions and provide valuable information for athletes, coaches, and sports organisations. The importance of analysing and identifying these factors lies in their potential to improve performance, prevent injuries and adapt training loads, thus favouring the achievement of short and long-term sporting goals.

Regarding CF, a systematic review by Meier et al. (2023) showed a great variety in the predictor variables analysed and wide discrepancies in the results. This highlights the diverse and unfamiliar nature of CF, reflecting the demands faced by these athletes and the difficulty for researchers in developing accurate performance prediction models (Meier et al., 2023).

The following sections detail the main factors identified as predictors of performance in different sports.

Anaerobic fitness as a predictor of sports performance.

PP determined by the WG test has been associated with speed skating performance (Hofman et al., 2017), and PP measured via the countermovement jump (CMJ) with Olympic weightlifting performance (Snatch and Clean & Jerk) in both male and female athletes (Zaras et al., 2020).

Likewise, in CF, PP measured with the WG has been shown to be related to performance in some of the tests such as the CrossFit® Total (Dexheimer et al., 2019), the scores of some WODs and final score of the 2019 CrossFit® Open (Martínez-Gómez et al., 2020), as well as in an AMRAP-type WOD (Bellar et al., 2015). In this line, PP measured via vertical jump has also been shown to be associated with CF performance, as all jump-related variables were highly associated with at least four of the five WODs and the final ranking of the 2019 Open (Martínez-Gómez et al., 2020).

XP measured with WG has shown to be a good predictor of performance in speed skaters (Hofman et al., 2017) and CF athletes (Martínez-Gómez et al., 2020).

Body composition (BC) as a predictor of sports performance

BC refers to the proportion of the different components of the human body. One of the most commonly used BC models in research is the 2-compartment model. It divides the body into two main components: fat mass (FM) and LBM. LBM includes everything that is not fat, such as muscle, bone, organs and water. In contrast, FM refers to the amount of fat tissue in the body. The proportion of each of these components varies according to the age, gender, ethnicity and physical activity level of each individual (Guo S et al., 1999; Kirchengast, 2010; Wulan et al., 2010). BC can be studied in total (whole body) or segmental (by region) values. Segmental BC measures the different components of BC by dividing the body into several anatomical regions, such as arms, legs, trunk and head. Segmental BC provides detailed information on body mass distribution and can help detect asymmetries. Accurate measurement of BC can provide valuable information on health, fitness and sports performance.

In sports, some components of BC are used to select, monitor, and predict athletes' performance throughout the year (Rudnev, 2020). BC can significantly affect athletic performance by influencing an athlete's strength, power (Ben Mansour et al., 2021), and agility (Corredor-Serrano et al., 2023). Some authors have studied the relationship between BC components and performance in different physical tests in athletes (Corredor-Serrano et al., 2023; García-Chaves et al., 2023; Kim et al., 2011). For this reason, BC has been classified as a predictive factor closely related to athletic performance in various sports.

For instance, excess FM has been shown to impact physical performance negatively (Lockie et al., 2021; G. T. Mangine et al., 2020; Vargas et al., 2018; Zeitz et al., 2020). On the contrary, LBM has been shown to be directly related to sports performance (Maciejczyk et al., 2015; Stephenson et al., 2015; Zaras et al., 2020). A higher LBM is associated with greater muscle strength and greater power development, which can improve performance in sports that require explosive strength, such as weightlifting (Zaras et al., 2020), football (Ishida et al., 2021; Triki et al., 2012), hockey (Chiarlitti et al., 2018), or water polo (Di Vincenzo et al., 2019).

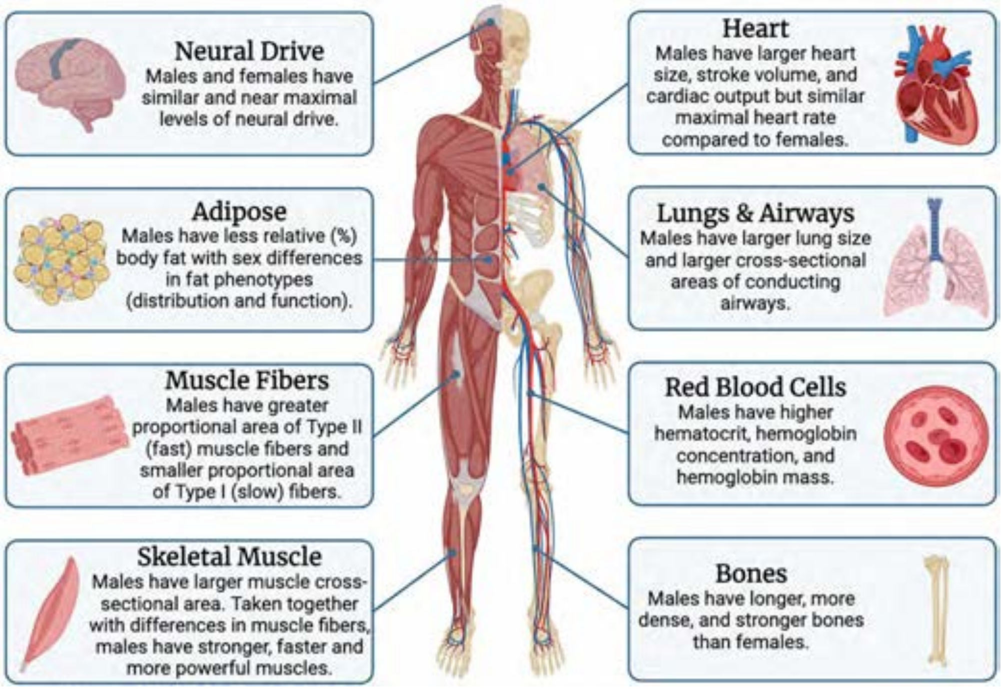
In the same way, a study on cross-country skiers found a significant correlation between LBM variables and sprint performance, both in men and women, but only in women in distance races (Carlsson et al., 2014).

In line with previous results, a higher amount of LBM and lower FM has been observed in higher-level CF athletes (G. T. Mangine et al., 2022; Meier et al., 2023), which may suggest the importance of these values in this sport's athletes.

Therefore, higher levels of LBM are associated with better anaerobic performance in athletes of multiple disciplines.

1.8. SEX DIFFERENCES

Biological sex has been identified as an influential factor in the performance differences between the sexes. These differences are attributed to specific anatomical and physiological differences between men and women in various body systems that determine the benefits or limits of physical performance in healthy and diseased individuals (Hunter & Senefeld, 2024; Landen et al., 2023). Figure 8 shows the biological differences between the sexes in the different systems.



Males and females have similar and near maximal levels of neural drive.

Males have less relative (%) body fat with sex differences in fat phenotypes (distribution and function).

Males have greater proportional area of Type II (fast) muscle fibers and smaller proportional area of Type I (slow) fibers.

Males have larger muscle cross-sectional area. Taken together with differences in muscle fibers, males have stronger, faster and more powerful muscles.

Males have larger heart size, stroke volume, and cardiac output but similar maximal heart rate compared to females.

Males have larger lung size and larger cross-sectional areas of conducting airways.

Males have higher hematocrit, hemoglobin concentration, and hemoglobin mass.

Males have longer, more dense, and stronger bones than females.

Figure 8. Illustration of the anatomical and physiological differences between men and women associated with differences in sports performance. From Hunter & Senefeld (2024)

Physiological differences

Multiple sex differences in athletic performance are attributed to exposure to high levels of endogenous testosterone in males during puberty, up to 15 times higher than in females. This hormone increases muscle mass, muscle fibre size, haemoglobin concentration, and overall strength and endurance development in males, but it remains low in females (Hunter et al., 2023; Hunter & Senefeld, 2024). These differences give men a significant advantage in activities that rely on muscular strength, power, speed and aerobic capacity (Hunter & Senefeld, 2024). Figure 9 shows sex differences in different physiological and morphological variables.

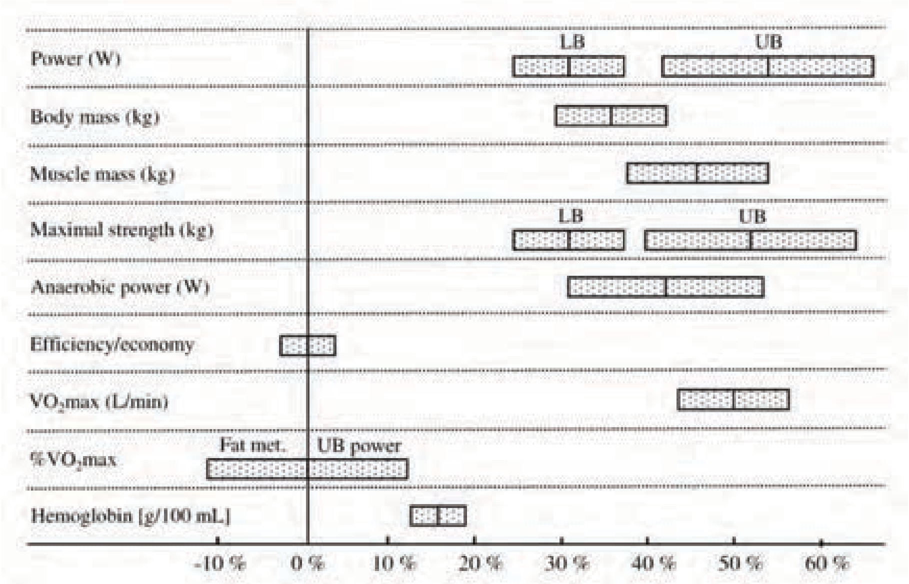


Figure 9. Sex differences in different physiological and morphological variables. From Sandbakk et al. (2018)

In addition to muscle fibre size, there are differences in the proportional area of fibre type (Bartolomei et al., 2021; Hunter & Senefeld, 2024; Nuzzo, 2022, 2023). Differences in muscle fibre type distribution may contribute to differences in strength, with ST fibres occupying a larger area in females and FT fibres in males. This difference could explain why women may have a higher resistance to fatigue in specific endurance tasks and lower strength than men, with women's strength presenting 50-60% of male upper body strength and 60-70% of the lower body (Nuzzo, 2022). Figure 10 represents the differences in strength between men and women.

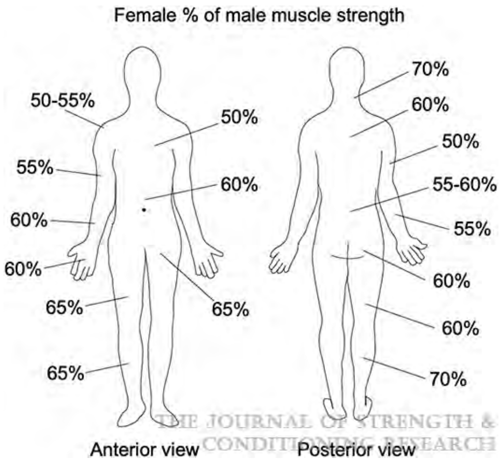


Figure 10. Differences between sexes in percentages of muscle strength in different muscle groups. Female values are presented as a percentage of male values. From Nuzzo (2022)

Some authors have suggested metabolic and substrate utilisation differences as explaining factors for some differences in limb muscle performance and fatigability (De Poli et al., 2019), although these differences have a minor impact on absolute performance in elite athletes (Hunter & Senefeld, 2024; Tortu & Deliceoglu, 2024). In elite athletes, although the contributions of the oxidative, glycolytic and ATP-PCr pathways have been shown to be similar between men and women, significant differences in total energy expenditure have been found (Tortu & Deliceoglu, 2024). Figure 11 shows each energy system's relative contributions and total expenditure in a WG test.

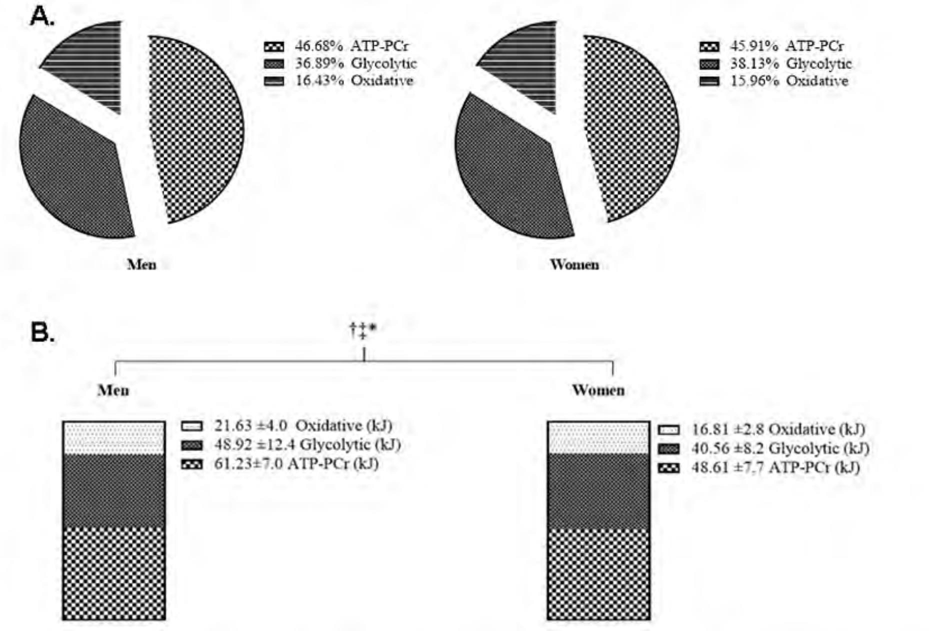


Figure 11. Comparison between sexes in the contribution of energy systems during the WG test (A) in relative and (B) absolute values. From Tortu & Deliceoglu (2024)

Morphological differences

Some authors have shown morphological differences between sexes in different populations. Bartolomei et al. (2021) found significant differences between men and women in different sports regarding LBM, with men having a 41.3% higher LBM than women. However, they did not observe significant differences in FM between sexes.

In cross-country skiers, Carlsson et al. (2014) showed significantly higher LBM and lower FM in men compared to women in whole body and several body segments, including arms, trunk and legs. The only exception was trunk fat mass, where no significant difference was observed.

Differences in anaerobic fitness

Several studies have shown significant differences in anaerobic performance between men and women assessed in different tests such as WG (De Poli et al., 2019; Gastin, 1994; Pennington, 2014; Tortu et al., 2024; Zebrowska et al., 2012), vertical jump (Pennington, 2014), pool-specific tests (Zera et al., 2022) and weightlifting like the back squat, deadlift and bench press (Bartolomei et al., 2021). In all tests, absolute power values were higher in males, indicating a consistent sex difference in maximal strength development in different environments.

In addition to absolute values, some authors have found significant differences in power values relative to body mass in snowboarders (Zebrowska et al., 2012) and martial arts practitioners (Tortu & Deliceoglu, 2024). However, when values are adjusted to LBM, differences are no longer significant in some tests (Maud & Shultz, 1986; Tortu & Deliceoglu, 2024), suggesting that the amount of LBM may largely determine anaerobic performance.

No comparison studies have been found on sex differences in anaerobic performance in CF athletes in various laboratory or field tests. Moreover, to determine such differences in absolute and relative values to body mass, LBM and MM during these all-out effort tests. Considering the significance of anaerobic fitness in CF, research in this area could help identify the determinants of such differences and provide valuable knowledge to professionals and researchers to design accurate assessment tools or specific training programmes.

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II. OBJECTIVES

"Goals transform a random walk into a chase."

Mihaly Csikszentmihalyi.

OBJECTIVES

Article 1

- To analyse the agreement between four anaerobic field tests against the reference test (Wingate).

Article 2

- To determine the total and segmental body composition values associated with anaerobic performance assessed in the Wingate test.

- To develop predictive models that better explain anaerobic performance variables and make comparisons between sexes.

Article 3

- To identify sex-based performance differences in absolute and relative values to body mass, LBM and MM during three all-out effort tests.

- To assess the consistency of the differences between the three tests.

III. METHODS, RESULTS AND DISSCUSSION

"If we knew what we were doing, it wouldn't be called research, would it?"

Albert Einsten.

3.1. Article 1:

THE ANAEROBIC POWER ASSESSMENT IN CROSSFIT® ATHLETES: AN AGREEMENT STUDY

ABSTRACT

Anaerobic power and capacity are considered determinants of performance and are usually assessed in athletes as a part of their physical capacities' evaluation along the season. For that purpose, many field tests have been created. The main objective of this study was to analyze the agreement between four field tests and a laboratory test. Nineteen CrossFit® (CF) athletes were recruited for this study (28.63 ± 6.62 years) who had been practicing CF for at least one year. Tests performed were: (1) Anaerobic Squat Test at 60% of bodyweight (AST60); (2) Anaerobic Squat Test at 70% of bodyweight (AST70); (3) Repeated Jump Test (RJT); (4) Assault Bike Test (ABT); and (5) Wingate Anaerobic Test on a cycle ergometer (WG). All tests consisted of 30 s of max effort. The differences among methods were tested using a repeated-measures analysis of variance (ANOVA) and effect size. Agreement between methods was performed using Bland–Altman analysis. Analysis of agreement showed systematic bias in all field test PP values, which varied between -110.05 ($AST60_{PP}$-WG_{PP}) and 463.58 (ABT_{PP}-WG_{PP}), and a significant proportional error in ABT_{PP} by rank correlation ($p < 0.001$). Repeated-measures ANOVA showed significant differences among PP values ($F(1.76,31.59) = 130.61$, $p = < 0.001$). In conclusion, since to our knowledge, this is the first study to analyze the agreement between various methods to estimate anaerobic power in CF athletes. Apart from ABT, all tests showed good agreement but cannot be used interchangeably in CF athletes. Our results suggest that AST and RJT are good alternatives for measuring the anaerobic power in CF athletes when access to a laboratory is not possible.

KEYWORDS: anaerobic power; peak power; HIFT; high-intensity functional training; CrossFit; athletes; field test

INTRODUCTION

Anaerobic capacity has been defined as the total amount of ATP re-synthesized, by the whole body, during a maximal intensity and short duration effort by means of the anaerobic metabolic pathways (Green, 1994). The time interval to best measure the anaerobic capacity is 30 s (Green, 1995) since up to 80% of the energy consumed in 30 s of maximal effort comes from anaerobic sources (Beneke et al., 2002; Smith & Hill, 1991). In addition, in a longer test, individuals tend not to apply the maximum intensity (Dal Pupo et al., 2014). There are several laboratory tests to assess the anaerobic performance (Vandewalle et al., 1987). However, most are expensive and difficult to perform due to the specific equipment they require. For that reason, one of the most widely used laboratory tests to assess this ability is the Wingate test, which consists of pedaling with arms or legs at maximum effort for 30 s against a resistance determined by the participant's body weight. WG has shown to be a reliable test, having a test-retest correlation in many populations ranging from 0.89 to 0.98 (Bar-Or, 1987). Two main variables are determined from this test, peak power (PP) and mean power (XP). PP is also known as "anaerobic power" and is determined by the peak mechanical power recorded during the test, normally occurring in the first 5 to 10 s. In addition, XP is considered by many authors as the "anaerobic capacity" and represents the average mechanical power maintained during the 30 s, taken at 1, 3 or 5 s periods (Bar-Or, 1987). Some authors have shown PP and XP to be associate with performance in some team and individual sports, especially those performed at high intensity or a combination of low-moderate intensities with higher intensity peaks such as CF (Martínez-Gómez et al., 2020), surfing (Farley et al., 2016), alpine ski (Miura, 2015), soccer (Sporis et al., 2009), track and field athletes (Çakir-Atabek, 2014) and many others.

In order to assess this ability out of the laboratory, numerous field tests, consisting of different exercises or tasks, have been created. Some of them based on different modalities of jumps (Çakir-Atabek, 2014; Dal Pupo et al., 2014; Krishnan et al., 2017; López-Segovia et al., 2014; Nikolaidis et al., 2016; Sands et al., 2004); running (Baker et al., 1993; Kimura et al., 2014; López-Segovia et al., 2014); squat exercise (Fry et al., 2014; López-Segovia et al., 2014; Luebbers & Fry, 2015); and other exercises such as skipping (Theophilos et al., 2016). All those tests have been studied in active individuals (Baker et al., 1993; Kimura et al., 2014; Theophilos et al., 2016; Zagatto et al., 2009) as well as athletes of different sports such as soccer (López-Segovia et al., 2014), volleyball (Dal Pupo et al., 2014; Nikolaidis et al., 2016), track and field (Bar-Or, 1987; Çakir-Atabek, 2014; Legaz-Arrese et al., 2011; Luebbers & Fry, 2015), and cyclists (Inoue et al., 2012; Queiroga et al., 2013). They have shown to be valid tools to assess these parameters in athletes (Çakir-Atabek, 2014; Dal Pupo et al., 2014; Kimura et al., 2014; Luebbers & Fry, 2015).

In the last decade, Functional Fitness Training has become one of the top fitness trends around the world (Kercher et al., 2021; Thompson, 2017). One of these functional fitness programs, which has developed into a competitive sport, was branded as CrossFit®. CF is a multimodal high-intensity functional training program that combines weightlifting, gymnastics and athletics, among other movements in just one training or competition bout and develops all physical domains such as endurance, strength, stamina, etc. (Feito et al., 2018). The multimodality characteristic of this sport, combined with the fact that the tests carried out in competition are not previously announced or standardized, means that CF athletes must be prepared for the unknown and therefore have an optimal development of all physical capacities such as maximum strength, stamina, power, speed, cardiorespiratory fitness, etc. (Butcher et al., 2015; Dexheimer et al., 2019; Escobar et al., 2017; Mangine, Stratton, et al., 2020; Mangine, Tankersley, et al., 2020; Martínez-Gómez et al., 2020; Shaw et al., 2015; Zeitz et al., 2020).

Additionally, its intensity component indicates that CF competitors must exhibit a great deal of anaerobic performance to excel in this sport (Mangine, Stratton, et al., 2020).

When a field test is developed to assess any ability of the athletes throughout the season, experts attempt to simulate the specific sporting gestures of the discipline for which it is created (running in soccer, for example). In the case of CF, as a multimodal sport made up of many elements of different kinds (squatting, jumping, running, lifting, etc.), it might seem challenging to succeed in choosing a specific exercise that encompasses all the skills and abilities necessary for this activity and evaluate any capacity accurately. Nevertheless, taking into account the specific characteristics of these athletes, it may be assumed that any field test might be a valid and interchangeable tool to assess any of the physical capacities. Hence, they might show a good performance in any test with jumping, running, cycling, squatting, etc.

In the current work, to assess the anaerobic performance by different exercises and determine their validity and level of agreement, four tests were chosen: a continuous jump test (RJT) used in previous work by Dal Pupo et al. (2014) as well as three other tests that, to our knowledge, have not been used previously: two weighted deep squat tests (AST60 and AST70) at different percentages of the athlete's bodyweight (60% and 70%) and a test performed with a particular machine used in CF where upper and lower limbs are used simultaneously called Assault Bike® (ABT).

In CF athletes, some authors have evaluated the physiological determinants of performance in (Butcher et al., 2015; Dexheimer et al., 2019; Escobar et al., 2017; Mangine, Tankersley, et al., 2020; Martínez-Gómez et al., 2020; Shaw et al., 2015; Zeitz et al., 2020). Most of them using laboratory tests to assess both the aerobic or anaerobic capacities and comparing the results with those obtained in standardized CF workouts. However, no study of agreement between field methods has been found. Therefore, the main purpose of this study is to analyze the agreement between four different modalities of field test measuring anaerobic performance (AST60, AST70, RJT and ABT) against the gold standard, Wingate test, in CF athletes.

MATERIALS AND METHODS

Participants

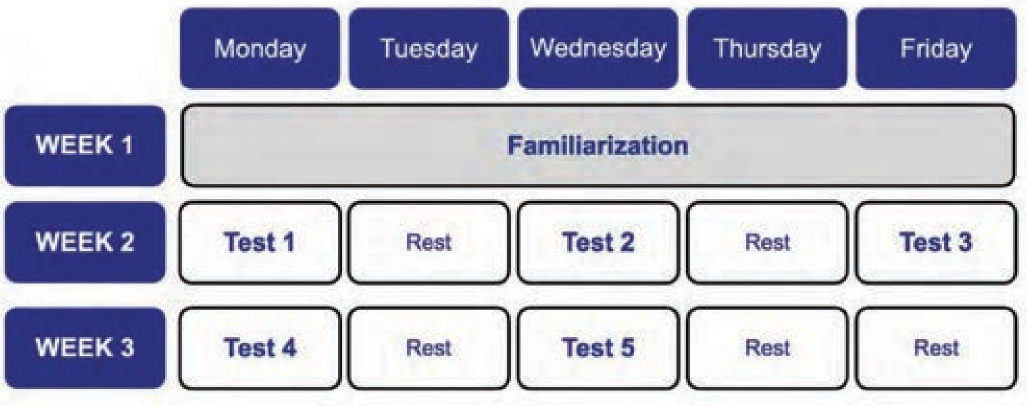
Nineteen CF participants volunteered to participate in this study, approved by Málaga University Ethics Committee (CEUMA: 43-2018-H). They were experienced athletes who followed the same competitors' training program and had competed in some national or international competition. Data collection was carried out over four weeks off-season. Except for the rest periods established before each test, the athletes followed their regular training regimen throughout those weeks. They were asked to stop taking any supplementation or performance-enhancing products one week prior to data collection. The participants were recruited and tested in a local CF center. All participants provided written informed consent. As inclusion criteria, a minimum of one year of CF practice was established. Any participants with the presence or suspicion of any cardiac pathology, suffering or having suffered recently any musculoskeletal injury or any other condition that prevented exercising properly were excluded. Descriptive data are shown in Table 1.

Table 1. Descriptive data of the sample (n = 19).

	Mean	SD
Age (years)	28.63	6.62
Height (cm)	176.18	5.34
Body Mass (kg)	81.67	6.43
Body Mass Index (kg/m^2)	26.29	1.34
Fat Mass (kg)	24.71	6.35
Fat Mass (%)	20.10	5.18
Muscle Mass (kg)	35.03	3.74
Muscle Mass (%)	42.87	2.69
Lean Body Mass (kg)	56.95	10.02
Lean Body Mass (%)	79.90	5.18

Study Design

A cross-sectional study was conducted over four weeks. Despite the fact that all participants were familiar with the exercises in all tests, a familiarization session was also scheduled during the first two weeks. All trials were separated by at least 48 h and per- formed at the same daytime to avoid the effects of circadian rhythms (Souissi et al., 2010). Participants were also advised to refrain from any strenuous physical activity in the previous 24 h of each trial. Tests performed were: 1) Anaerobic Squat Test at 60% of bodyweight (AST60); 2) Anaerobic Squat Test at 70% of bodyweight (AST70); 3) Repeated Jump Test (RJT); 4) Assault Bike Test (ABT); and 5) Wingate Anaerobic Test on a cycle ergometer (WG). Tests order execution was randomly assigned. The chronology of the tests is shown in Figure 12.



	Monday	Tuesday	Wednesday	Thursday	Friday
WEEK 1	Familiarization				
WEEK 2	Test 1	Rest	Test 2	Rest	Test 3
WEEK 3	Test 4	Rest	Test 5	Rest	Rest

Figure 12. Chronology of the tests

Procedures

Anthropometry, Body Composition and other Physiological Variables

On the first day, to detect any possible cardiac pathology, all participants underwent an electrocardiogram assessed by a qualified physician. Furthermore, some anthropo- metric data were taken; height, by a wall-mounted stadiometer (SECA® 206; SECA, Hamburg, Germany) with a precision of 1 mm and body mass, by a scale with a precision of 100 gr (SECA® 803; SECA, Hamburg, Germany). Additionally, body composition was measured by a Medisystem Multifrequency Impedanciometer (Sanocare Human System SL, Madrid, Spain). Participants were asked to go fasting or without consuming any drink or food for at least 4 h, not having consumed alcohol in the last 48 h nor diuretics in the last 7 days or having performed strenuous physical activity in the previous 12 h (Alvero-Cruz et al., 2010). Before the measure, they remained supine for 5 min with the upper limbs positioned about 30 degrees apart from the trunk and the lower limbs about 45 degrees apart (Kyle et al., 2004). Fat mass in kg was estimated according to Segal's formula (Segal et al., 1988), Lean body mass in kg was calculated by subtracting fat mass from total body mass and muscle mass in kg according to Janssen's formula (Janssen et al., 2000). Body composition variables were also calculated as a percentage (Table 1).

All-Out Anaerobic Tests

Anaerobic Squat Test (AST60 and AST70)

The AST consisted of 30 s at the maximum effort of deep squats with a percentage of the participant bodyweight. The maximum number of squats had to be performed within that interval. Deep squat was established as a squat in which the iliac crest is below the highest part of the knee in its lowest position, and the leg, thigh and trunk segments are fully aligned at the highest position (Figure 13). The equipment used was a standard olympic lifting set composed of a 20 kg barbell, plates between 5 and 15 kg, with increases of 5 kg, and fractional discs from 0.5 and 2.5 kg, with 0.5 kg increments, from Xenios Usa® (Xenios Usa LLC, New York, NY, USA). The power of each repetition was registered by Beast® accelerometry sensor (Beast technologies) attached to the participant's wrist through a bracelet "ad hoc" (see Figure 14) and data processed by its smartphone application. Beast® sensor has shown to be a valid and reliable tool to measure full-squat values (Balsalobre-Fernández et al., 2017). Two trials with different loads were executed, 60% (AST60) and 70% (AST70) of participant bodyweight. Participants were weighed before each trial to determine the barbell load, rounded to the closest 0.5 kg. As a warm-up, they started with five minutes easy run, followed by one set of ten repetitions with an empty barbell, two more sets of ten repetitions with the assigned percentage and finished with 5 min easy run. Afterwards, a 5 min interval for recovery was established and used to set the accelerometry sensor. At the count of 3, 2, 1... "Go!" the participant began to work at maximum effort, trying to execute as many squats as possible, being verbally motivated by the examiner throughout the test. To cool down, they were asked to easy walk for 5 min. PP, XP and MP were determined. FI, understood as the loss of power during the 30 s interval, was calculated by the following formula FI (%) = (PP-PM/PP) * 100 (Bar-Or, 1987).

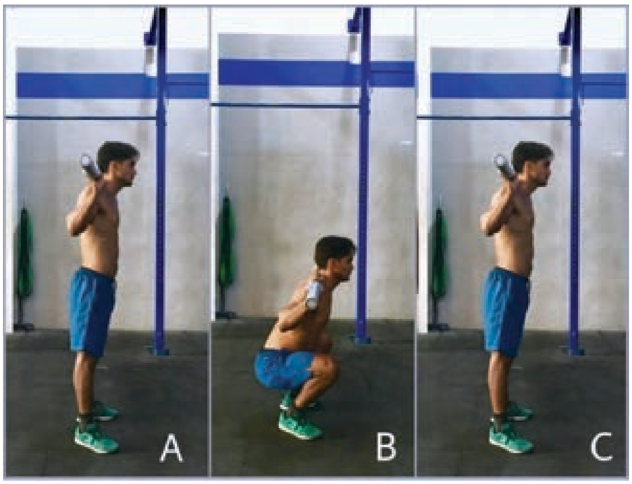


Figure 13. Full squat movement requirements. A: start position; B: lowest position and C: final position.

<u>Repeated Jump Test (RJT)</u>

As previously described by Dal Pupo et al. (2014), this test consisted of the maximum number of countermovement jumps in 30 s at the maximum height. Before the trial, participants warmed up with 5 min easy run, 3 sets of 10 forward jumps, 3 sets of 5 vertical jumps and 5 additional minutes easy run. Afterwards, a 5 min interval was established to rest and set the sensors. At the count of 3, 2, 1... "Go!" the participant started to jump as high and fast as possible. In order to keep the maximum intensity, the participant was encouraged by the researchers during the whole interval. Right after the test, they were asked to easy walk for 5 min to calm down. Jumping variables were registered by a Polar® V800 with Running Bluetooth® Smart. This sensor has been shown to be valid and reliable to determine jumping variables (Garnacho-Castaño et al., 2021). PP, XP, MP and FI were determined.

Figure 14. Beast sensor placement on the athlete's right wrist.

Assault Bike Test (ABT)

This test was performed with an Assault Bike® Classic model (Assault Fitness Products; California, USA). The Assault Bike® is an air-resisted bike with the peculiarity of using both upper and lower extremities simultaneously (Figure 15). This machine has gained its popularity by being used by most CF centers and official competitions worldwide. The test consisted of 30 s at maximal effort. It began with a 15 min warm-up of cycling at 50 rpm (approximately 176 watts). Next, a 5 min recovery interval was established. The test was carried out from a static position without any inertia. To facilitate the initial start, the crank of the dominant leg was previously set to 45 degrees.

At the count of 3, 2, 1... "Go!" the participant started to ride as fast as possible. In order to keep the maximum intensity, the researcher motivated them verbally during the whole interval. A 5 min recovery interval ride at a warm-up pace was set to calm down. Power values were registered every 5 s. PP, obtained by PP(W)= maximal power output in the first 10 s; XP calculated by XP(W) = $\sum$ of each 5 s Power(W)/6; MP, as MP(W) = minimal power output in the last 10 s, and FI were determined.

Figure 15. Assault Bike® Classic

Wingate Anaerobic Test (WG)

The WG test is considered the gold standard when measuring the anaerobic capacity and consists of 30 s at maximum speed on a cycle ergometer with a constant resistance of 0.075 kp per kg bodyweight (Bar-Or, 1987). The test was executed with a Monark 828E cycle ergometer (Monark Exercise AB, Vansbro, Sweden) calibrated before each trial. Since trials were completed in morning-time (between 9:00 am and 2:00 pm), the warm-up was extended from 5 to 15 min, as proposed by Souissi et al. (2010). To warm up, all participants were asked to ride at 50–70 rpm at 1 kp (50–70 watts) for 15 min. Afterwards, they took a 5 min recovery interval. Straightaway, at the count of “3, 2, 1... Go!” the participant started to ride as fast as possible. The researcher motivated them verbally during the whole time. A 5 min recovery ride at a warm-up pace was set to calm down. Every 5 s, power values were registered. PP, XP, MP and FI were determined.

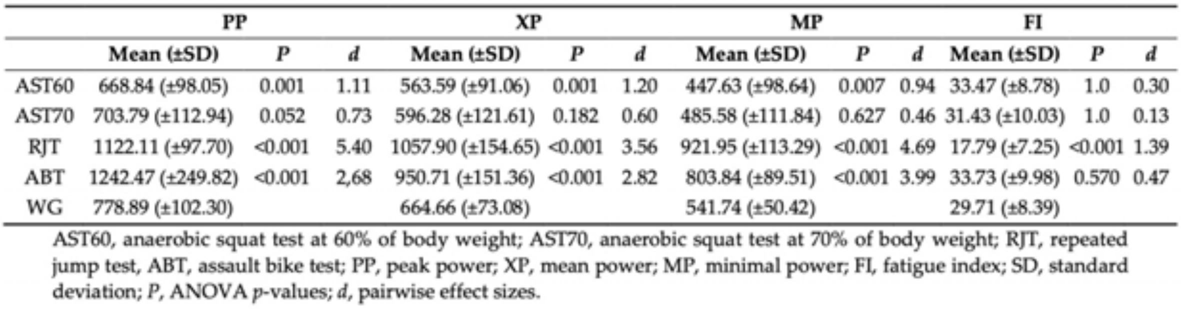
Statistical Analysis

The Statistical Package for the Social Sciences (SPSS 21, IBM Corp., Armonk, NY, USA) and MedCalc Statistical Software (MedCalc 18.6, MedCalc Software Ltd., Ostend, Belgium) were used to carry out statistical analyses. The level of significance was set at $p \leq 0.05$. Data were checked for normality by the Shapiro–Wilks analysis, and the agreement for the PP of the four methods was performed by using Bland–Altman analysis (Bland & Altman, 1986). In order to evaluate the proportional error, Tau Kendall's rank correlation of the difference and mean of every method paired with WG was carried out. Previously, variables of difference and mean were computed for each pair. Furthermore, the differences among PP, XP, MP and IF of the five methods were tested for statistical significance ($p < 0.05$) using a repeated-measures analysis of variance (ANOVA). When a significant difference was found, post hoc 2-tailed paired t-tests to determine which values were significantly different were used. The Bonferroni adjustment was applied to keep the overall significance level at 0.05. The assumption of sphericity was tested using Mauchly's test. Additionally, the pairwise effect size was calculated by Cohen's d using G*Power 3.1.9.6 software.

RESULTS

All variables showed a normal distribution in Shapiro–Wilks analysis ($p = >0.05$), except for RJTXP ($p = 0.001$) and RJTMP ($p = 0.022$). Since the sphericity was violated, Greenhouse–Geisser corrected results are reported ($\varepsilon = 0.44$). The repeated-measures ANOVA showed significant differences among PP values, ($F(1.76,31.59) = 130.61$, $p = <0.001$). Pairwise effect sizes are shown in Table 2. Additionally, absolute PP, XP and MP values of the AST60 and AST70 tests were slightly lower than the reference test. AST60 PP, XP and MP underestimated WG values by −110.05 (−14.12%), −101.07 (−15.20%) and −94.11 (−17.37%) watts, respectively. AST70 also underestimated WG values by −75.11 (−9.64%), −68.38 (−10.29%) and −56.16 (−10.37%) watts. In addition to the minor underestimation, the differences between AST70 and WG remained quite regular among all power values, around 10%, which was the only test that showed not statically significant differences by ANOVA test and showed the smallest effect size in all variables (Table 2).

Table 2. Absolute values of peak, mean, minimal power and fatigue index of the tests.



	PP			XP			MP			FI		
	Mean (±SD)	*P*	*d*	Mean (±SD)	*P*	*d*	Mean (±SD)	*P*	*d*	Mean (±SD)	*P*	*d*
AST60	668.84 (±98.05)	0.001	1.11	563.59 (±91.06)	0.001	1.20	447.63 (±98.64)	0.007	0.94	33.47 (±8.78)	1.0	0.30
AST70	703.79 (±112.94)	0.052	0.73	596.28 (±121.61)	0.182	0.60	485.58 (±111.84)	0.627	0.46	31.43 (±10.03)	1.0	0.13
RJT	1122.11 (±97.70)	<0.001	5.40	1057.90 (±154.65)	<0.001	3.56	921.95 (±113.29)	<0.001	4.69	17.79 (±7.25)	<0.001	1.39
ABT	1242.47 (±249.82)	<0.001	2,68	950.71 (±151.36)	<0.001	2.82	803.84 (±89.51)	<0.001	3.99	33.73 (±9.98)	0.570	0.47
WG	778.89 (±102.30)			664.66 (±73.08)			541.74 (±50.42)			29.71 (±8.39)		

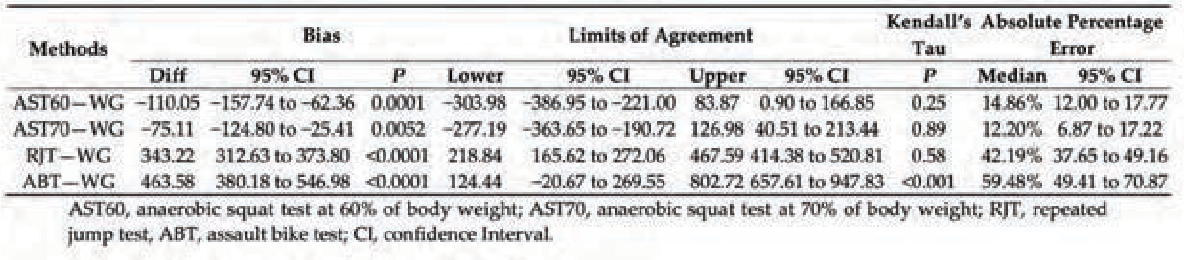
AST60, anaerobic squat test at 60% of body weight; AST70, anaerobic squat test at 70% of body weight; RJT, repeated jump test, ABT, assault bike test; PP, peak power; XP, mean power; MP, minimal power; FI, fatigue index; SD, standard deviation; *P*, ANOVA *p*-values; *d*, pairwise effect sizes.

In contrast, the homologous absolute values RJT and ABT were notably higher. With an overestimation of RJT values of 343.22 (44.06%), 393.24 (59.16%) and 380.21 (70.18%), and ABT values of 463.58 (59.52%), 286.05 (43.04%) and 262.10 (48.38%) (Table 2).

In addition, Bland–Altman's analysis of agreement showed systematic bias in all field test PP values ($p > 0.05$). The smallest difference between all PP values and WGPP was observed for the AST70 with an underestimation of −75.11 watts (95% CI, −124.80, −25.41). AST60 also underestimated PP by −110.05 watts (95% CI, −157.74, −62.36). Nevertheless, the other two tests, RJT and ABT, overestimated PP by 343.22 watts (95% CI, 312.63, 373.80) and 463.58 watts (95% CI, 380.18, 546.98), respectively.

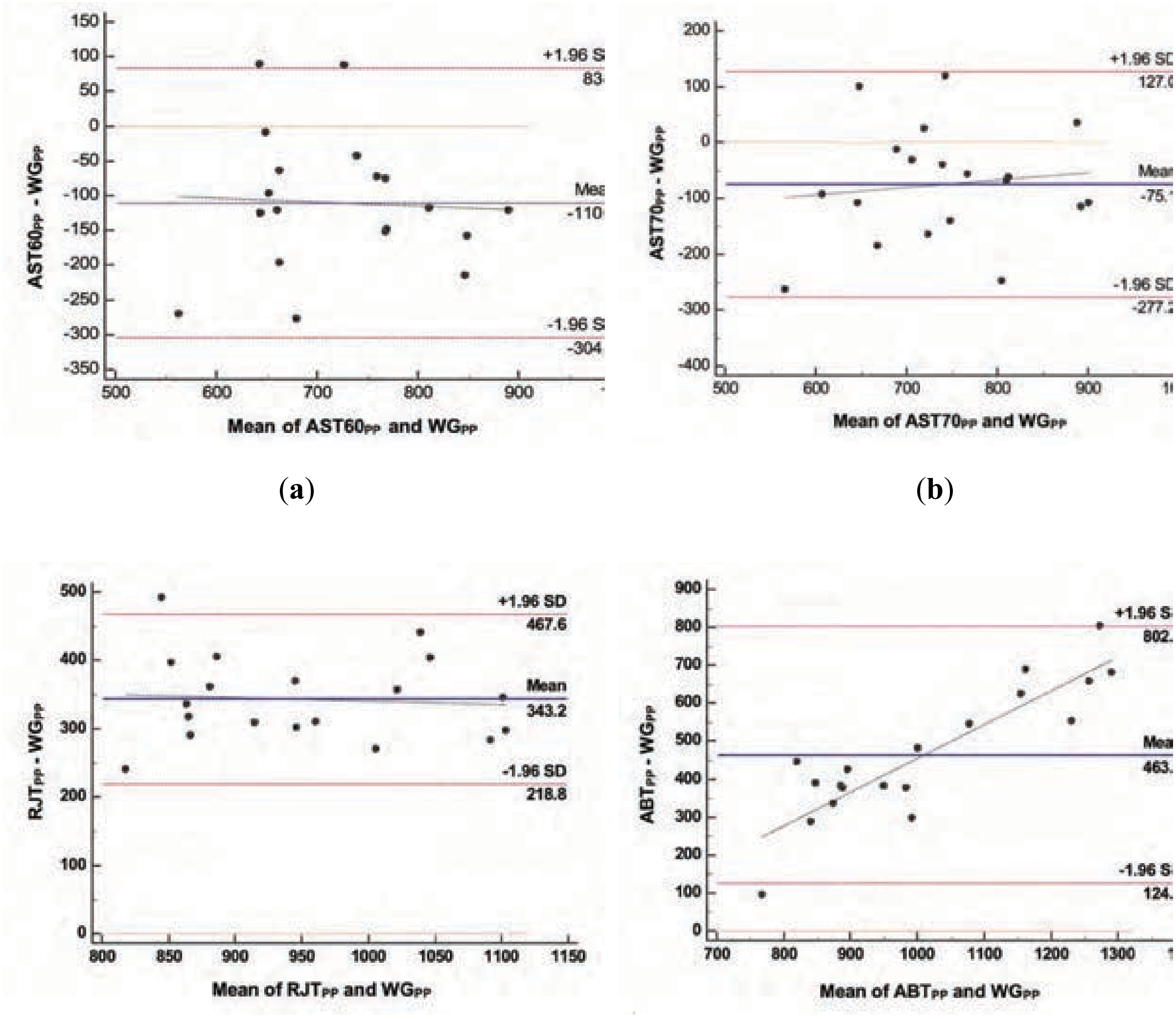
Furthermore, only a significant proportional error was found in ABTPP by Tau Kendall's rank correlation (Table 3 and Figure 16d).

Table 3. Agreement analysis results.



Methods	Bias			Limits of Agreement				Kendall's Tau	Absolute Percentage Error	
	Diff	95% CI	P	Lower	95% CI	Upper	95% CI	P	Median	95% CI
AST60−WG	−110.05	−157.74 to −62.36	0.0001	−303.98	−386.95 to −221.00	83.87	0.90 to 166.85	0.25	14.86%	12.00 to 17.77
AST70−WG	−75.11	−124.80 to −25.41	0.0052	−277.19	−363.65 to −190.72	126.98	40.51 to 213.44	0.89	12.20%	6.87 to 17.22
RJT−WG	343.22	312.63 to 373.80	<0.0001	218.84	165.62 to 272.06	467.59	414.38 to 520.81	0.58	42.19%	37.65 to 49.16
ABT−WG	463.58	380.18 to 546.98	<0.0001	124.44	−20.67 to 269.55	802.72	657.61 to 947.83	<0.001	59.48%	49.41 to 70.87

AST60, anaerobic squat test at 60% of body weight; AST70, anaerobic squat test at 70% of body weight; RJT, repeated jump test, ABT, assault bike test; CI, confidence Interval.



(**a**) (**b**)

(**c**) (**d**)

Figure 16. Bland–Altman's plots representing differences (Y axes) and mean (X axes) of measurements between: (a) AST60 and WG; (b) AST70 and WG; (c) RJT and WG; (d) ABT and WG.

DISCUSSION

The main purpose of the present study was to evaluate the agreement between the five methods to assess anaerobic power in CF athletes. Since to our knowledge, this is the first study to analyze the agreement between various methods to estimate anaerobic power in CF athletes. Bland–Altman's analysis revealed a systematic bias with a mean difference that can vary between −110.05 watts (AST60PP−WGPP) and 463.58 Watts (AB- TPP−WGPP).

Despite the systematic bias shown by all the field tests compared with the laboratory test, the results showed good agreement between all methods ($p > 0.05$) since more than 80% of the dots on the graph were within the limits of agreement. In contrast, Tau Kendall's rank correlation analysis showed a proportional error in ABTPP ($p < 0.001$), where the differences were small for low PP values in the range of measurements and become higher as the true value increases. Additionally, the lowest within-subject variability in all the variables studied in the present work suggests that the AST70 is a valid field test to assess the power and anaerobic capacity in CF athletes.

Some of the field tests practiced in this study, such as AST and ABT, have not been previously used. AST is a test based on the squat exercise tested with two different percentages of the participants' body mass (60 and 70). The underestimation of PP absolute values, supported by the findings of Luebbers & Fry (2015), suggests that it might be interesting to replicate the study using higher percentages (75 and 80) to achieve more accurate agreement. In addition, some studies have shown underestimation of absolute values in a running test assessed in armed forces operators (Theophilos et al., 2016) and cycling athletes (Queiroga et al., 2013), as well as a kicking test studied in taekwondo athletes (Rocha et al., 2016). On the other hand, the overestimation of the RJT PP value is consistent with the findings of Sands et al. (2004), where absolute power values of the Bosco test were higher than WG. In our study, overestimation was also found in ABT, and it might be due to the simultaneous use of lower and upper limbs to generate power instead of only the lower limbs as in WG. We have not found any previous study carried out with this machine that can provide data in this regard. However, the simultaneous use of the muscles of the lower limbs involved in pedaling and those of the upper limbs involved in pulling and pushing may suggest a more significant muscle mass implication and thus a greater capacity to generate power.

The results abovementioned are consistent with the WGPP differences reported by Gacesa et al. (2009) in a comparison testing of maximum anaerobic performance on different elite athletes. Their findings suggest that the ability to generate power may be dependent on the activity since the highest values were found in anaerobic predominant sports such as volleyball, basketball, hockey, boxing, and wrestling, and lower values in soccer, rowing, and long-distance running athletes, which are predominantly aerobic types of sports. Further, some authors have found differences in power values between participants of different positions in basketball (Pojskić et al., 2015) and elite runners of different distances (Legaz-Arrese et al., 2011). Consequently, it might be thought anaerobic power to be related to specific disciplines or attributed to some degree of specificity of the athletes tested. However, the results shown in the present study, due to the need of CF athletes to face multiple physical demands with a high level of intensity, may indicate that these athletes are able to exhibit outstanding anaerobic performance in tests of different nature (jumping, squatting, cycling, etc.).

Many comparisons or validity studies where authors studied the level of agreement between only one field test and WG were found. However, a lack of agreement works between more than one field method and the laboratory test in the literature makes it difficult to compare our results with any other. Moreover, as mentioned above, most of their results show some level of under or overestimation of field-test values which may be attributable to the biomechanical, technical or any other difference in the sporting gesture used for each test together with the intrinsic characteristic of the athlete tested. Future studies analyzing the agreement between different task tests may be of interest to find the cause of that variability and the most suitable field test for each discipline, especially in a multimodal sport as it is CF.

One limitation of the present work was not considering any other variables, such as kinematics, that could reflect the different biomechanical or lifting strategies related to performance in AST or any other test. Future research should aim to record these variables mentioned above and evaluate the interaction in the outcomes, replicating this work with other tests composed by other CF-specific exercises or in athletes of different experience/fitness levels.

In practice, the use of AST70 or RJT as a method to assess the anaerobic power in CF athletes could provide an alternative for coaches interested in assessing or monitoring their athletes at any point of the season without the need of taking them to a sports medicine laboratory.

CONCLUSIONS

Since to our knowledge, this is the first study to analyze the agreement between various methods to estimate anaerobic power in CF athletes. In conclusion, our results show a good level of agreement between all four methods and WG, being greater in AST70. However, they may not be used interchangeably. Moreover, the proportional error found in ABT might make its use doubtful. Moreover, the results of the present study suggest that the magnitude of peak power values seems to be de- pendent on the type of exercise and athlete characteristics.

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3.2. Article 2:

THE ASSOCIATION OF WHOLE AND SEGMENTAL BODY COMPOSITION AND ANAEROBIC PERFORMANCE IN CROSSFIT® ATHLETES: SEX DIFFERENCES AND PERFORMANCE PREDICTION

ABSTRACT

The main purpose of this study was to establish the association between total and segmental body composition (BC) variables and anaerobic performance and to create optimal models that best predict such performance in CrossFit® (CF) athletes. Fifty athletes, 25 males and 25 females (age: 33.26 ± 6.81 years; body mass: 72.57 ± 12.17 kg; height: 169.55 ± 8.71 cm; BMI: 25.06 ± 2.31 kg·m−2) were recruited to participate and underwent BC analysis using dual-energy X-ray absorptiometry (DXA) and an all-out laboratory test on a cycle ergometer (Wingate) to determine their anaerobic performance. The results show a significant correlation between BC values and performance, ranging from moderate ($r = -0.34$, $p = 0.015$) to near-perfect ($r = 0.96$, $p < 0.01$). Furthermore, the created performance prediction models exhibited predictive capacities ranging from 19% ($p = 0.017$) to 93% ($p < 0.001$). All prediction models were created using total or segmental lean mass variables, excluding others. The studied body composition and performance variables found significant differences between males and females. The findings demonstrate that body composition variables are crucial indicators of anaerobic performance in CF athletes. In this regard, it may be advisable for sports performance professionals to consider this information when monitoring athletes throughout the season or designing specific training programs. Similarly, the use of predictive equations could be a useful tool for estimating peak and mean power values.

KEYWORDS: sports performance, anaerobic performance, body composition, athletes, CrossFit®, high-intensity functional training

INTRODUCTION

Body composition (BC) refers to the ratio of the different components of the human body. One of the most widely used body composition models in research is the 2-compartment model. It divides the body into two main components: fat mass and fat-free mass, also known as Lean Body Mass (LBM), which includes everything that is not fat in the body, such as muscle, bone, organs, and water. Instead, fat mass refers to the amount of adipose tissue in the body. The proportion of each of these components varies according to an individual's age, gender, ethnicity, and physical activity level (Guo S et al., 1999; Kirchengast, 2010; Wulan et al., 2010). BC can be studied in total values (of the whole body) or segmentally (by regions). Segmental BC measures body composition, dividing the body into various anatomical regions, such as the arms, legs, trunk, and head. Segmental BC provides detailed information on body mass distribution and can help assess body asymmetry. The applications of BC are diverse and range from health evaluation to the design of personalized training and nutrition programs. Therefore, accurate measurement of BC can provide valuable information about health, fitness, and sports performance.

In sports, some BC components are used as a selection method, monitoring throughout the year, and predicting athletes' performance (Rudnev, 2020). In addition, athletes and coaches are aware of the importance of BC in sports performance and injury prevention (Lukaski & Raymond-Pope, 2021) since BC can significantly affect athletic performance by influencing an athlete's strength, power (Ben Mansour et al., 2021) and agility. Some authors have studied the relationship between some of the components of BC and performance in different physical tests in athletes (Corredor-Serrano et al., 2023; García-Chaves et al., 2023; Kim et al., 2011; Pearson et al., 2019). For example, excess fat mass has been shown to have a negative impact on physical performance (Lockie et al., 2021; Mangine et al., 2020; Vargas et al., 2018; Zeitz et al., 2020). Similarly, lean body mass (LBM) has been shown to be directly related to athletic performance (Maciejczyk et al., 2015; Stephenson et al., 2015; Zaras et al., 2020). Higher LBM is associated with greater muscle strength and power performance, which can improve performance in sports that require explosive strength, such as weightlifting (Zaras et al., 2020), soccer (Ishida et al., 2021; Triki et al., 2012), hockey (Chiarlitti et al., 2018) or water polo (Di Vincenzo et al., 2019). Thus, higher levels of LBM are associated with better anaerobic performance.

Anaerobic performance refers to the capacity of the human body to generate energy quickly and efficiently during high-intensity and short-duration activities, ranging from 1 second (e.g., maximum Olympic lift, 100-meter sprint) to 100 seconds (e.g., 400-meter sprint), predominantly through anaerobic metabolic pathways (ATP-phosphocreatine and anaerobic glycolysis). Even in short maximal efforts of 30 seconds, there is a contribution from aerobic systems of approximately 16-18% (Beneke et al., 2002; Smith & Hill, 1991). Anaerobic performance is characterized by two key aspects: power and capacity. Anaerobic power refers to the maximum peak power that an individual can generate during a short-duration maximal effort, typically observed within the exertion's first 5-10 seconds. On the other hand, anaerobic capacity is defined as the average power that can be sustained throughout the effort. These components of anaerobic performance are associated with the ability to perform explosive actions such as sprints, jumps, throws, or maximum lifts, as well as the capacity for rapid recovery between repeated efforts. They have been shown to be determining factors for performance in high-intensity sports and those with predominantly lower intensity but intermittent peaks of higher intensity. Therefore, improving anaerobic performance can be fundamental for competitive success in individual and team sports that demand intense and intermittent efforts (Bellar et al., 2015; Franchini, 2023; Gacesa et al., 2009; Hofman et al., 2017; Losnegard et al., 2012).

The prediction of performance through prediction equations has been addressed by several authors in different populations (Alvero-Cruz et al., 2019; Lara-Sánchez et al., 2011; Stickley et al., 2012). Equations have been developed for prediction of different expressions of performance such as peak vertical jump power through jump height (Lara-Sánchez et al., 2011), for estimation of trail running time through VO2 max and fat mass percentage (Alvero-Cruz et al., 2019), even for estimation of peak and mean power of the Wingate test (WG) through tests without subjecting participants to any physical exertion (Stickley et al., 2012). These prediction equations can be valuable tools for sports performance professionals to estimate specific performance parameters of athletes without subjecting them to maximal effort tests.

In recent years, one high-intensity sport that has experienced exponential growth and attracts an increasing number of participants each year is commercially known as CrossFit® (CF) (Feito et al., 2018). CF has become a trendy sport with thousands of affiliated centers worldwide and numerous competitions where athletes must demonstrate their physical capabilities in various unknown tests over a few days, typically a weekend. Its main characteristics lie in the multimodal nature of its training or competition events, combining exercises from gymnastics, Olympic weightlifting, running, jumping, and lifting or carrying of heavy objects performed at high intensities. This high-intensity component inherent in this sport necessitates athletes to exhibit good anaerobic performance (Bellar et al., 2015). Likewise, in other sports, BC can play a significant role in the performance of these athletes. Therefore, it would be essential to determine the optimal values that enhance their capacities and assist them in achieving the best results.

Several authors have attempted to determine the predictors of performance in official CF tests, also called WOD (from workout of the day) (Butcher et al., 2015; Mangine et al., 2020, 2022; Mangine & McDougle, 2022; Zeitz et al., 2020). However, significant heterogeneity in the investigated performance and BC variables makes formulating definitive and appropriate conclusions challenging. Therefore, the main objective of this study is to determine the total and segmental BC values associated with anaerobic performance, measured using a widely employed standard laboratory test (Wingate). Secondary objectives include developing prediction models that best explain the dependent performance variables and conducting comparison between sexes. We hypothesized that both total and segmental body composition would be associated with anaerobic performance, and sex differences would be present.

MATERIALS AND METHODS

Participants

Fifty CF athletes from various local centers were recruited to participate in the current study, 25 men (age: 33.32 ± 5.83 years; body mass: 82.76 ± 7.47 kg; height: 176.90 ± 4.16 cm; BMI: 26.43 ± 2.03 kg·m^{-2}) and 25 women (age: 33.20 ± 7.78 years; body mass: 62.37 ± 5.50 kg; height: 162.20 ± 5.01 cm; BMI: 23.70 ± 1.70 kg·m^{-2}). All participants voluntarily agreed to take part after responding to an advertisement posted at these centers. The primary inclusion criterion was a minimum of one year of CF practice. Individuals with any recent musculoskeletal injuries or medical conditions that could hinder their ability to perform the maximum effort test, such as cardiac issues, were excluded from the study.

Study Design

A cross-sectional study was conducted over four weeks, in which participants underwent three separate sessions with a minimum of 48 hours between each session. The first session involved a personal interview to provide volunteers with comprehensive information about all procedures, record sociodemographic data, obtain informed consent, and familiarize them with the performance test. The second session included anthropometric measurements and BC analysis, while the final session was dedicated to performing the maximum effort test. Participants were advised to refrain from engaging in strenuous physical activity within 24 hours before the all-out test. All procedures were conducted in accordance with the principles outlined in the Declaration of Helsinki and had received prior approval from the ethics committee at the University of Málaga (43-2018-H). Participants were fully informed beforehand and provided written consent. Figure 17 shows the algorithm of the study protocol.

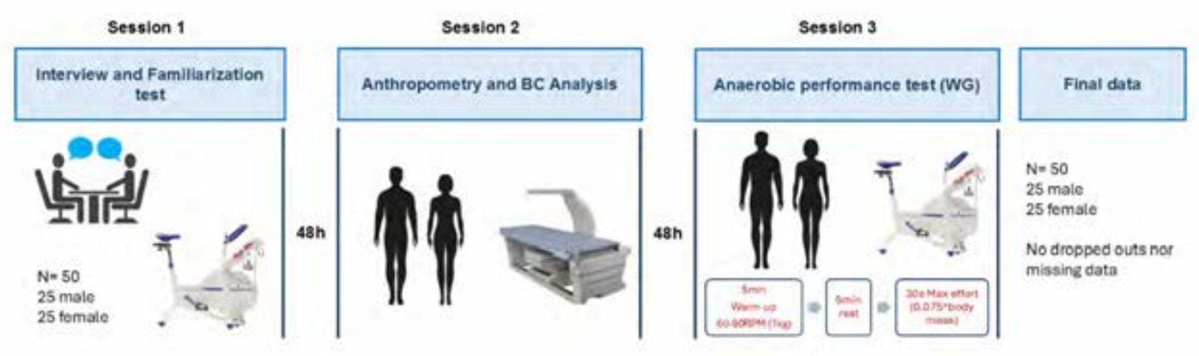

Figure 17. Study protocol.

Anthropometrics & Body Composition Analysis

During the second session, all participants were asked to come to the laboratory, where their height in cm was measured using a wall-mounted stadiometer with a precision of 1 mm (SECA® 206; SECA, Hamburg, Germany), and their body mass in kilograms was measured using a scale with a precision of 100 g (SECA® 803; SECA, Hamburg, Germany). Subsequently, body composition analysis was conducted using dual-energy X-ray absorptiometry (DXA) (Horizon A, Hologic Inc., Bedford, MA, USA). Data were processed using Hologic APEX software (version 4.6) integrated into the measuring instrument. Athletes were instructed to arrive at the laboratory fasting, having abstained from eating or drinking for at least 4 hours and consuming alcohol within the past 24 hours or diuretics within the previous week in accordance with Alvero-Cruz et al. (2010). Other authors have previously used this method of BC analysis in CF athletes (Carreker & Grosicki, 2020; Sauvé et al., 2024).

From the data provided by the system software, the variables of total lean body mass (WBLM), total fat mass (WBFM), and percentage of body fat (WBFMP) were extracted. Values of the trunk, upper limbs, and lower limbs were used for segmental body composition. Absolute values or the average of the percentages of both the right and left limbs were summed for the upper and lower limbs. Head values were excluded from the segmental analysis. Final segmental BC variables used were: trunk lean mass in kg (TRLM), trunk fat mass in kg (TRFM), percentage of trunk fat mass (TRFMP), upper extremity lean mass in kg (UELM), upper extremity fat mass in kg (UEFM), percentage of upper extremity fat (UEFMP), lower extremity lean mass in kg (LELM), lower extremity fat mass in kg (LEFM), and percentage of lower extremity fat (LEFMP). All values reported in grams by the software were converted to kilograms.

Anaerobic Performance

Anaerobic performance was measured using the Wingate Anaerobic Test (WG) with a resistance of 0.075 kp per kg body mass (Bar-Or, 1987). This test was chosen because it has been shown to have a significant relationship with performance in various official CF events (Butcher et al., 2015; Menargues-Ramírez et al., 2022). The test was conducted using a Monark 894E cycle ergometer (Monark Exercise AB, Vansbro, Sweden). To determine peak (WGPP), mean (WGXP), and minimum power output (WGMP), power values were recorded every 5 seconds. A first familiarization test was carried out during the study's first session.

Statistical Analysis

The statistical package for the social sciences (SPSS 26, IBM Corp., Armonk, NY, USA) and the statistical software MedCalc (MedCalc 18.6, MedCalc Software Ltd., Ostend, Belgium) were used for statistical analyses. Descriptive statistics (mean and standard deviation) were calculated for all variables. Normality of the variables was assessed using the Shapiro-Wilk test. As some variables did not meet the assumption of normality, the relationships between all independent variables and anaerobic performance were quantified by calculating Spearman's Rho correlation coefficients. The strength of the observed relationships was interpreted using the following criteria: trivial (<0.10), small (0.10–0.29), moderate (0.30–0.49), high (0.50–0.69), very high (0.70–0.90), or nearly-perfect (>0.90) (Alsamir Tibana et al., 2019). Independent samples t-tests were conducted to assess differences between male and female athletes. Effect sizes for sex comparisons were calculated using Cohen's d (d). According to Cohen (1988), effect size values were interpreted as small (d = 0.2), medium (d = 0.5), or large (d = 0.8). The statistical significance level for all tests was set at $p < 0.05$. Finally, stepwise multiple regression analyses were performed to determine the relationship between the independent and dependent variables and to create models that best explained the variance of the anaerobic performance variables. A stepwise multiple linear regression analysis was conducted for each dependent variable (WGPP, WGXP and WGMP) using total or segmental body composition data. The significant variables selected by the statistical software were used to create a predictive model for the performance variables.

RESULTS

Table 4 presents descriptive statistics for the entire group and for males and females, along with the comparison between sexes and the effect size of all study variables. Table 2 presents correlation data between all variables.

Table 4. Descriptive data of the variables, sex comparison and effect size.

	Group (n=50)			**Male (n=25)**			**Female (n=25)**				
	Mean	**SD**	**SEM**	**Mean**	**SD**	**SEM**	**Mean**	**SD**	**SEM**	**t**	***d***
Age (years)	33.26	6.81	0.96	33.32	5.84	1.17	33.20	7.78	1.56	0.951	0.02
Body Mass (kg)	72.57	12.17	1.72	82.76	7.47	1.49	62.37	5.50	1.10	0.000	3.11
Height (cm)	169.55	8.71	1.23	176.90	4.16	0.83	162.20	5.01	1.00	0.000	3.20
BMI (kg·m^{-2})	25.06	2.31	0.33	26.43	2.03	0.41	23.70	1.70	0.34	0.000	1.46
WBLM (kg)	58.20	12.15	1.72	69.01	6.15	1.23	47.39	4.46	0.89	0.000	4.02
WBFM (kg)	15.49	3.14	0.44	15.15	3.25	0.65	15.82	3.05	0.61	0.459	0.21
WBFMP (%)	21.45	4.95	0.70	17.95	3.09	0.62	24.96	3.86	0.77	0.000	2.01
TRLM (kg)	27.24	5.49	0.78	32.14	2.77	0.55	22.35	2.00	0.40	0.000	4.06
TRFM (kg)	6.26	1.77	0.25	6.72	1.94	0.39	5.79	1.47	0.29	0.062	0.54
TRFMP (%)	18.80	4.46	0.63	17.14	3.91	0.78	20.47	4.42	0.88	0.007	0.80
UELM (kg)	7.02	2.19	0.31	8.99	1.13	0.23	5.05	0.65	0.13	0.000	4.27
UEFM (kg)	1.68	0.38	0.05	1.69	0.38	0.08	1.67	0.39	0.08	0.855	0.05
UEFMP (%)	20.25	5.94	0.84	15.73	2.51	0.51	24.77	4.82	0.96	0.000	2.35
LELM (kg)	20.45	4.28	0.61	24.10	2.44	0.49	16.80	1.91	0.38	0.000	3.33
LEFM (kg)	6.46	1.57	0.22	5.55	1.18	0.24	7.37	1.38	0.28	0.000	1.41
LEFMP (%)	24.55	7.04	1.00	18.67	3.32	0.66	30.42	4.29	0.86	0.000	3.06
WGPP (W)	700.93	224.08	31.69	895.41	135.75	27.15	506.45	72.75	14.55	0.000	3.57
WGXP (W)	511.58	160.89	22.75	653.11	91.80	18.36	370.06	51.92	10.38	0.000	3.80
WGMP (W)	311.27	112.64	15.93	387.99	101.22	20.24	234.55	58.28	11.66	0.000	1.86
WGFI (%)	54.84	10.31	1.46	56.59	9.24	1.85	53.09	11.20	2.24	0.235	0.34

SD: standard deviation; SEM: standard error of the mean; t: significance of t-student analysis; *d*: Cohen d effect size; BMI: body mass index; WBLM: whole body lean mass in kg; WBFM: whole body fat mass in kg; WBFMP: whole body fat mass as percentage; TRLM: trunk lean mass in kg; TRFM: trunk fat mass in kg; TRFMP: trunk fat mass percentage; UELM: upper extremity lean mass in kg; UEFM: upper extremity fat mass in kg; UEFMP: upper extremity fat mass as percentage; LELM: lower extremity lean mass in kg; LEFM: lower extremity fat mass in kg; LEFMP: lower extremity fat mass as percentage; WGPP: peak power in watts; WGXP: mean power in watts; WGMP: minimal power in watts; WGFI: fatigue index.

Correlations

Table 5 shows the correlations of the group variables and the sample split by sex. Total lean mass (WBLM) and segmental lean mass of the trunk (TRLM), upper extremity (UELM), and lower extremity (LELM) showed significant positive correlations with all anaerobic performance variables (WGPP, WGXP and WGMP) in both the total and sex-separated samples. Likewise, significant negative correlations were found between total fat mass percentage (WBFMP) and segmental fat mass percentage of the trunk (TRFMP), upper extremity (UEFMP) and lower extremity (LEFMP) with all performance variables (WGPP,

WGXP and WGMP) only when the sample was considered as a single group. Furthermore, lower extremity fat mass in kilograms (LEFM) showed significant negative correlations with all performance variables in the pooled sample.

Table 5. Spearman's correlation coefficient between total and segmental body composition and the anaerobic power values in the whole group, male and female athletes.

	Group (n=50)			Male (n=25)			Female (n=25)		
	WGPP	WGXP	WGMP	WGPP	WGXP	WGMP	WGPP	WGXP	WGMP
WBLM (kg)	0.93**	0.96**	0.82**	0.72**	0.83**	0.59**	0.69**	0.82**	0.59**
WBFM (kg)	-0.03	-0.02	-0.1	0.32	0.3	0.11	0.01	0.06	-0.1
WBFMP (%)	-0.68**	-0.68**	-0.64**	0.01	-0.05	-0.13	-0.26	-0.26	-0.3
TRLM (kg)	0.91**	0.94**	0.81**	0.69**	0.79**	0.54**	0.56**	0.74**	0.63**
TRFM (kg)	0.25	0.27	0.19	0.23	0.26	0.12	0.01	0.06	-0.08
TRFMP (%)	-0.34*	-0.35*	-0.35*	0.04	0.02	-0.1	-015	-0.16	-0.26
UELM (kg)	0.91**	0.94**	0.81**	0.57**	0.71**	0.52**	0.67**	0.80**	0.57**
UEFM (kg)	0.06	0.11	0.06	0.38	0.45*	0.23	-0.11	0.04	-0.01
UEFMP (%)	-0.73**	-0.72**	-0.64**	0.08	0.03	-0.04	-0.39	-0.29	-0.23
LELM (kg)	0.93**	0.95**	0.80**	0.77**	0.83**	0.59**	0.69**	0.74**	0.46*
LEFM (kg)	-0.47**	-0.48**	-0.50**	0.21	0.15	0.01	0.01	0.08	-0.05
LEFMP (%)	-0.79**	-0.79**	-0.71**	-0.09	-0.16	-0.21	-0.34	-0.33	-0.29

WBLM: whole body lean mass in kg; WBFM: whole body fat mass in kg; WBFMP: whole body fat mass as percentage; TRLM: trunk lean mass in kg; TRFM: trunk fat mass in kg; TRFMP: trunk fat mass percentage; UELM: upper extremity lean mass in kg; UEFM: upper extremity fat mass in kg; UEFMP: upper extremity fat mass as percentage; LELM: lower extremity lean mass in kg; LEFM: lower extremity fat mass in kg; LEFMP: lower extremity fat mass as percentage; WGPP: peak power in watts; WGXP: mean power in watts; WGMP: minimum power in watts; *Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed).

Multiple Regression Analysis

Table 6 presents the multiple regression models developed based on total and segmental BC using data from the entire group. The results demonstrate that the strongest predictor of total BC variables is WBLM, explaining 90% (F(1,48) = 421.066, p <0.001), 93% (F(1,48) = 692.025, p <0.001), and 63% (F(1,48) = 84.261, p <0.001) of the variance in WGPP, WGXP, and WGMP values, respectively. Regarding segmental BC, a model for WGPP is generated through LELM, accounting for 88% (F(1,48) = 371.044, p <0.001) of the variance. For WGXP, a model explained by LELM is developed with a predictive capacity of 91% (F(1,48) = 503.624, p <0.001). Finally, for WGMP, two different models are developed, model 1 explained by LELM, with a prediction capacity of 61% of its variance (F(1,48) = 78.299, p <0.001) and model 2 using UELM, accounting for 62% of its variance (F(1,48) = 80.764, p <0.001).

Table 6. Multiple regression models of the whole group using whole and segmental body composition

Dependent variable	Independent variable	Coefficient	Std. Error	P	VIF	R^2	R^2-ajusted
Whole Body Composition							
WGPP	Constant	-277.109				0.90	0.90
	WBLM	16.726	0.815	<0.001	1		
WGXP	Constant	-229.002				0.94	0.93
	WBLM	12.699	0.483	<0.001	1		
WGMP	Constant	-98.142				0.64	0.63
	WBLM	7.000	0.763	<0.001	1		
Segmental Body Composition							
WGPP	Constant	-268.458				0.89	0.88
	LELM	47.173	2.449	<0.001	1		
WGXP	Constant	-218.682				0.91	0.91
	LELM	35.628	1.588	<0.001	1		
WGMP (model 1)	Constant	-91.794				0.62	0.61
	LELM	19.610	2.216	<0.001	1		
WGMP (model 2)	Constant	38.810				0.63	0.62
	UELM	38.540	4.288	<0.001	1		

WGPP: peak power in watts; WGXP: mean power in watts; WGMP: minimal power in watts; WBLM: whole body lean mass in kg; LELM: lower extremity lean mass in kg; UELM: upper extremity lean mass in kg; VIF: variance inflation factor

Table 7 presents regression models for the dependent variables, classified by sex. Prediction models based on WBLM were developed based on total body composition. These models explain 57% (F(1,23) = 32.253, p < 0.001) and 42% (F(1,23) = 18.456, p < 0.001) of the variance in WGPP, 72% (F(1,23) = 63.222, p < 0.001) and 65% (F(1,23) = 46.432, p < 0.001) of the variance in WGXP, and 27% (F(1,23) = 9.743, p = 0.005) and 19% (F(1,23) = 6.668, p = 0.017) of the variance in WGMP for males and females, respectively.

When considering segmental body composition, prediction models were developed for both sexes, revealing a significant contribution from LELM. In the case of WGPP, LELM accounts for 59% (F(1,23) = 35.848, p < 0.001) and 47% (F(1,23) = 22.219, p < 0.001) of the variance in males and females, respectively.

Similarly, for WGXP, LELM contributes to 70% (F(1,23) = 56.030, p < 0.001) and 60% (F(1,23) = 37.615, p < 0.001) of the variance in males and females, respectively.

Table 7. Multiple regression models of by sex using whole and segmental body composition,

Dependent variable	Independent variable	Coefficient	Std. Error	P	VIF	R^2	R^2-ajusted
Whole Body Composition							
WGPP (male)	Constant	-109.973				0.58	0.57
	WBLM	14.435	2.542	<0.001	1		
WGPP (female)	Constant	-8.726				0.44	0.42
	WBLM	10,872	2.531	<0.001	1		
WGXP (male)	Constant	-234.243				0.73	0.72
	WBLM	12.812	1.611	<0.001	1		
WGXP (female)	Constant	-80.568				0.67	0.65
	WBLM	9.510	1.396	<0.001	1		
WGMP (male)	Constant	-168.543				0.30	0.27
	WBLM	8.007	2.565	0.005	1		
WGMP (female)	Constant	-58.676				0.23	0.19
	WBLM	6.188	2.396	0.017	1		
Segmental Body Composition							
WGPP (male)	Constant	-8.697				0.61	0.59
	LELM	37.131	6.202	<0.001	1		
WGPP (female)	Constant	57.947				0.49	0.47
	LELM	26.693	5.663	<0.001	1		
WGXP (male)	Constant	-114.627				0.71	0.70
	LELM	31.721	4.238	<0.001	1		
WGXP (female)	Constant	10.341				0.62	0.60
	LELM	21.409	3.491	<0.001	1		
WGMP (male)	Constant	-115.630				0.31	0.28
	LELM	20.730	6.380	0.004	1		
WGMP (female)	Constant	-99.744				0.27	0.23
	TRLM	14.960	5.199	0.009	1		

WGPP: peak power in watts; WGXP: mean power in watts; WGMP: minimal power in watts; WBLM: whole body lean mass in kg; LELM: lower extremity lean mass in kg; TRLM: trunk lean mass in kg; VIF: variance inflation factor.

For WGMP in males, LELM was also selected as an independent variable, explaining 28% (F(1,23) = 10.558, p = 0.004) of the variance. Conversely, in the case of females, the independent variable TRLM was chosen for model creation, explaining 23% (F(1,23) = 8.278, p = 0.009) of its variance.

Sex differences

Table 1 displays the sex differences observed among male and female athletes. The t-test results indicated statistically significant differences between sexes for most of the variables examined ($p < 0.05$). Conversely, a few variables did not exhibit statistically significant differences ($p > 0.05$), namely age, WBFM, TRFM, and UEFM. The most notable differences were the significantly higher correlations in men than in women. Conversely, the total and segmental body fat percentage was higher in women than men, especially in the lower extremities. Likewise, the prediction models developed show a more significant predictive capacity in men than women.

DISCUSSION

The main purpose of this study was to determine the relationship between BC values and anaerobic performance in CF athletes. The results of our work reveal a significant positive correlation between WBLM, TRLM, UELM and LELM with all studied anaerobic performance variables (WGPP, WGXP, and WGMP). The percentages of total or segmental fat mass in all segments (WBFMP, TRFMP, UEFMP, and LEFMP), as well as LEFM, showed a significant negative correlation with WGPP, WGXP, and WGMP when the sample was considered as a single group.

Concerning LBM, these results are consistent with those published by other authors in studies conducted on different populations. Maciejczyk et al. (2015) found a positive correlation between LBM and PP and XP in a 20-second maximal effort cycling test in a sample of physically active men. Similarly, Stephenson et al. (2015) demonstrated a significant correlation between WBLM and segmental LELM values and performance in vertical jump, in 102 non-athlete adults. Furthermore, a study conducted on motorcycle racing riders found a significant positive correlation between LBM and WGPP (Michalik et al., 2022). Other findings, such as those of Collins et al., (2022) showed a significant positive correlation between LBM and PP, vertical jump, and medicine ball throw in law enforcement officer recruits.

In CF athletes, Mangine et al. (2022) found a significant negative correlation between lean mass and the completion time of a standard WOD called "Fran," which involves performing a specified task as fast as possible. Therefore, athletes with higher LBM values completed the WOD in less time. Menargues-Ramírez et al. (2022) found a relationship between MM determined through skinfold measurements and the total weight lifted in another standard workout. These findings support the idea that LBM is positively related to anaerobic performance in different populations and sporting contexts.

Regarding FM, our results show a negative effect on performance, agreeing with those shown in other works that report a significant positive correlation between the WBFMP and skating times in male and female hockey players indicating that lower fat percentage is associated with faster times (Czeck et al., 2021) and a significant negative correlation between the values of total and segmental FM and anaerobic performance in female handball players (Kale & Akdoğan, 2020) or performance variables in other physical tests in recruits for law enforcement (Collins et al., 2022). Similarly, other studies conducted on CF athletes show similar results in which the percentage of FM negatively affects performance in different standard CF WODs, such as the "Open 19.1", described in the study conducted by Zeitz et al. (2020), all the events from the 2018 Open (Mangine et al., 2020), the time of the workout called "Fran" (Mangine et al., 2022), as well as the performance in another well-known WOD called "Murph" in which the subjects with the lowest percentage of FM showed better performance achieving the event in less time (Carreker & Grosicki, 2020). Like LBM, these results highlight the relevance of the role of FM in athletic performance, emphasizing its significant influence on athletes' ability to achieve optimal levels of power and endurance.

The results presented in our work show that the absolute values of lean mass accurately predict anaerobic performance among CF athletes. The goodness of fit of the prediction models developed in this study ranges from 61% to 93% (for minimum and peak power, respectively) by the WBLM values of the pooled sample (men and women together). The prediction equations obtained were WGPP = -277.109 + 16.726*WBLM (R^2= 0.90); WGXP = -229.002 + 12.699*WBLM (R^2= 0.93); WGMP = -98.142 + 7*WBLM (R^2 = 0.63).

For developing the prediction models of the whole group based on the segmental BC, the absolute values of LELM are included for three of the four models elaborated. As the only predictor of the WGPP and WGXP explaining 88% and 91% of their variances, respectively. Equations for these models are WGPP = -268.458 + 47.173*LELM (R^2 = 0.88) and WGXP = -218.682 + 35.628*LELM (R^2 = 0.91). For the prediction of the WGMP, two different models were obtained: model 1 by LELM, which explains 61% of its variance and model 2, explained by UELM, providing a goodness of fit of 62%. Developed equations are WGMP(model 1) = -

91.794 + 19.610*LELM (R^2 = 0.61) and WGMP(model 2) = 38.810 + 38.540*UELM (R^2 = 0.62).

When the sample is divided by sex, the prediction models substantially decrease their predictive capacities, varying between 21% in men and 19% in women of the prediction model created for the WGMP and 67% in men and 65% in women for the WGXP, both created through the WBLM. In the same way as for the whole group, using the segmental body composition values, almost all the models were created by the LELM, except for the prediction of the WGMP in women executed through the TRLM. The goodness of fit of these models ranges from 23% to 66%. An interesting aspect to consider is the improvement in the predictive capacity of the models made with the segmental BC variables compared to those of the total body when the sample is split by gender. This variation could be explained by the differences between men and women in the amount and distribution of lean mass or the contribution of other variables not recorded in the present study. Finally, in the sex comparison of our study, significant differences were found in all performance variables. These differences have been previously published by some authors such as Maud & Shultz (1986), who found significant differences between sexes in the absolute power values in the Wingate test, or Collins et al. (2022), who found significant differences between men and women in all performance variables except for maximum repetitions of push-up and the multi-station fitness test. In addition, statistically significant differences were found in all BC variables except for WBFM, TRFM, and UEFM. However, significant differences were found between sexes when expressing these same variables as a percentage (WBFMP, TRFMP and UEFMP). This discrepancy can be attributed to the use of the percentage value since it provides a more individually standardized parameter instead of a simple absolute value in kg. Likewise, the significant difference observed in the LELM value between both sexes could be associated with a greater amount of lean mass and a lower amount of segmental fat in the lower limbs of male athletes compared to their female counterparts. In addition, our results are consistent with those published by Collins et al. (2022), who found significant differences in the WBLM, as well as TRLM, UELM, and LELM, but found no differences in the variables of total or segmental FM between male and female law enforcement recruits. Using DXA as a method of analysis, Sanfilippo et al. (2019) also found significant differences between sexes in different sports, where men showed a higher LBM and lower FM.

The present study has several limitations that need to be considered. Firstly, the timing of the menstrual cycle in female athletes was neither considered nor recorded, nor was the use of contraceptive pills during the study and their potential effects on the results of BC analysis or performance in the maximal effort test. Also, the prediction models' low predictive capacity in women could raise doubts about the sample size used in this group. Second, dietary habits or food intake were not recorded in the days leading up to and during the study duration. This information could be important for better understanding the influence of nutrition on the obtained results. Third, the fatigue state before the max effort tests was not recorded, which might impact the results of these assessments.

Furthermore, it is essential to acknowledge that using laboratory tests in a controlled environment does not fully simulate the real competitive situations that athletes face in this sport. The absence of external factors and the lack of competitive pressure may limit the results' applicability under actual conditions.

Lastly, this study was cross-sectional, without establishing a cause-effect relationship between body composition values and anaerobic performance. Future intervention studies are needed to identify the effects of changes in lean mass and fat values on power and anaerobic capacity and identify other factors contributing to a more comprehensive explanation of these effects.

The findings of this research suggests that leaner CF athletes demonstrate superior performance, implying that an increase in lean mass could substantially improve their performance. These results provide valuable information for CF coaches to consider the possibility of focusing their training programs on increasing lean mass and reducing fat mass to enhance these athletes' performance. However, future research should aim to determine the optimal balance between lean and fat mass, avoiding excessive lean mass gains or extreme reductions in fat mass that may surpass the optimal levels and become counterproductive or detrimental to health.

Furthermore, the prediction equations developed in this study for body composition show a high predictive capacity. They could be used for estimating power and anaerobic capacity in CF athletes at specific time points or monitoring these parameters throughout the season. Thus, body composition assessment can be a valid tool, providing healthcare professionals, coaches, and fitness practitioners with an alternative method of evaluating anaerobic performance without exposing athletes to maximal effort tests.

CONCLUSIONS

We can conclude that our findings show a moderate to nearly-perfect relationship between lean body mass and total and segmental body fat percentage with anaerobic performance in CF athletes. Furthermore, considering the high goodness of fit of the prediction models developed in this study, we can report that total and segmental lean mass values are strong predictors of maximum and mean power determined in the Wingate test. However, due to the multiple factors that can contribute to performance, the specific predictive value of the regression models developed in this study should be interpreted with caution. The mentioned parameters can be reliable and cost-effective tools to aid in identifying athletes' potential and monitoring their fitness levels throughout the season.

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3.3. Article 3:

SEX DIFFERENCES IN ANAEROBIC PERFORMANCE IN CROSSFIT® ATHLETES: A COMPARISON OF THREE DIFFERENT ALL-OUT TESTS

ABSTRACT

Background

Athletic performance can be influenced by various factors, including those related to biological sex. Various scientific disciplines have studied the observed differences in athletic performance between men and women. Moreover, anaerobic performance refers to the capacity of the human body to generate energy quickly and efficiently during high-intensity and short-duration activities. It is associated with the ability to perform explosive actions and the capacity for rapid recovery between repeated efforts. Anaerobic performance is a determining factor for performance in high-intensity sports and those with predominantly lower intensity but intermittent peaks of higher intensity. One high-intensity sport that has experienced exponential growth and attracts increasing numbers of participants yearly is commercially known as CrossFit® (CF). Therefore, the primary purpose of this study was to determine the anaerobic performance differences between sexes in CF athletes in terms of absolute and relative values.

Methods

A cross-sectional study was conducted over 2 weeks. Fifty CrossFit® athletes (25 men and 25 women) voluntarily participated in the study. They were subjected to body composition analysis and three maximal effort tests to measure anaerobic performance: a cycle ergometer test, a continuous jump test and a squat test.

Results

Significant differences were found in all the variables of absolute peak power and relative to body mass in the three tests. In values adjusted to lean and muscle mass, significant differences were only found in the cycle ergometer test but not in the other two. In mean power variables, significant differences were found in all the variables studied, except for the mean power adjusted to muscle mass in the squat test. In conclusion, this study’s results indicate that differences between sexes in absolute and relative peak powers measured in all tests evaluated are explained by the amount of lean and muscle mass. However, mean powers show significant differences in all variables except for the one related to muscle mass in the squat test.

KEYWORDS: Sports performance, anaerobic performance, body composition, athletes, CrossFit®, high-intensity functional training

INTRODUCTION

Sports performance may be influenced by various factors, including biological sex. Differences in performance between men and women have been studied in fields such as anatomy, physiology, and sports science (Dominelli & Molgat-Seon, 2022; Hübner-Woźniak et al., 2004; Hunter, 2016; Lepers, 2019; Lomauro & Aliverti, 2021; Nuzzo, 2023; Rosa-Caldwell & Greene, 2019; Schlegel & Křehký, 2022). Increasing interest exists in studying the causes behind these differences, with morphological and physiological characteristics playing a potential role in influencing athletic outcomes. Previous research shows that men generally exhibit higher anthropometric values (weight, height, limb length, muscle perimeters, etc.) than women, which may affect the kinematics and efficiency of sports actions (Podstawski et al., 2020). Body composition (BC) is another important factor in athletic performance. Men have more muscle or lean mass and less body fat than women on average (Maud & Shultz, 1986; Perez-Gomez et al., 2008). These differences may provide men with an advantage in certain sports, as BC values are related to performance (Mayhew et al., 2001; Potteiger et al., 2010; Stephenson et al., 2015). Additionally, men's greater absolute strength may be attributed to muscle mass quantity and muscle fiber distribution (Nuzzo, 2022). However, strength (Bishop et al., 1987) and anaerobic performance (Maud & Shultz, 1986) differences decrease when adjusted for body or lean mass. Furthermore, men have been shown to have a greater high-intensity exertion capacity, possibly due to differences in the utilization of aerobic and anaerobic metabolic pathways (Hill & Smith, 1993), as well as differences in BC (Maciejczyk et al., 2015; Mayhew et al., 2001).

One high-intensity sport that has gained recent popularity for its multidisciplinary approach is CrossFit® (CF). This fitness program focuses on constantly varied functional movements performed at high intensity (Feito et al., 2018), aiming to enhance overall fitness and performance across multiple physical domains. Its comprehensive conditioning method has earned recognition in scientific and sports communities.

High intensity is related to anaerobic performance in athletes due to the physiological adaptations induced by high-intensity training (Franchini et al., 2016). Accurate assessment methods of anaerobic performance are important tools for sports professionals. Specific tests have been developed to measure power and anaerobic capacity. In the laboratory, ergometric tests, such as the Wingate (WG) (Bar-Or, 1987; Smith & Hill, 1991) and in-field tests with vertical jump (Dal Pupo et al., 2014; Nikolaidis et al., 2016) and sprint (Zagatto et al., 2009) have been designed to assess power and anaerobic capacity.

Field-based tests have significant advantages over laboratory tests in assessing anaerobic performance in athletes. They simulate more realistic and sport-specific situations and offer greater measurement specificity. These tests are generally more accessible and affordable, allowing more athletes to be evaluated more efficiently. Their lower cost also makes them accessible to coaches with limited budgets or without access to sports medicine laboratories. Due to CF's multimodal nature and varied movements and exercises, researchers and coaches find it challenging to select a single test to assess performance accurately. Numerous studies have analyzed anaerobic performance using laboratory and field tests across various sports and movements, including cycling, running, and jumping (Andrade et al., 2015; Fry et al., 2014; Miura, 2015; Zagatto et al., 2009).

Some studies have examined the relationship between specific laboratory tests and standard CrossFit® workouts (WODs) (Butcher et al., 2015; Dexheimer et al., 2019; Martínez-Gómez et al., 2019) correlated values from a deep squat-based field test to performance in the 2017 CrossFit® Open. Schlegel & Křehký (2022) also compared gender differences in performance during the 2011 CrossFit® Games. The agreement between peak power ratings from various tests in male CF athletes has also been investigated (Ponce-García et al., 2021). However, studies have not been found on sex differences in anaerobic performance across multiple sport-specific tests in these athletes. Therefore, this study aims to identify sex-based performance differences in absolute and relative values of body mass, lean body mass, and muscle mass during maximal effort tests, assess the consistency of these differences across homologous test values, and compare findings with other sports or populations. Understanding these differences may be important for optimizing training program design and scaling.

MATERIALS AND METHODS

Study design

A cross-sectional study was conducted over 2 weeks. Participants underwent three sessions of performance assessment and one session of BC assessment in the laboratory. In the first session, they underwent BC analysis, and in the subsequent sessions, they underwent maximal exercise testing. All sessions were separated by 48 h.

Participants

Fifty CF athletes participated voluntarily in the present study. Twenty-five males (mean ± SD; age 33.32 ± 5.84 years, height 176.9 ± 4.16 cm, body mass 82.76 ± 7.47 kg) and twenty-five females (mean ± SD; age 33.20 ± 7.78 years, height 162.2 ± 5.01 cm, body mass 62.37 ± 5.50 kg). The sample size was established through statistical power analysis. They were recruited from an advertisement circulated among CF centers owners in Malaga and surrounding areas. Inclusion criteria were that participants had to train at least 3 h per week and had been practicing CF for at least 1 year. All participants were informed of the procedures and provided written informed consent. The procedures in the present study followed the rules of the Helsinki Declaration and were approved by the ethics committee of the University of Malaga.

Anthropometry and body composition

Participants were called to the laboratory for anthropometric measurements and BC analysis in the first session. They were asked to come fasting or not to have eaten or drunk anything for at least 4 h, not to have consumed alcohol in the last 24 h, and not to have taken diuretics in the last week. Their height was measured with a wall-mounted stadiometer accurate to 1 mm (SECA® 206; SECA, Hamburg, Germany), and their mass with a balance accurate to

100 g (SECA® 803; SECA, Hamburg, Germany). Subsequently, BC analysis was performed by dual-energy X-ray absorptiometry (DXA) (Hologic Inc., Bedford, MA, USA) using Hologic APEX software (version 4.6) and electrical bio-impedance (InBody 770, Cerritos, CA, USA). Lean and muscle mass in kilograms were extracted from the BC variables. Muscle mass isolated as a single variable assessed by electrical bio-impedance was included. Its inclusion aimed to compare whether results exclusively on muscle mass, the physiologically active part isolated from lean mass (excluding bones and viscera), made any difference compared to those calculated based on lean mass.

All-out tests

To assess anaerobic performance, three maximal 30-s effort tests were performed: a cycle ergometer test (WG), a repeated jumps test (RJT), and a squat test (AST). The absolute values of peak (PP), mean (XP), and minimum power (MP) were determined for all tests. The fatigue index (FI) was calculated, obtained from the percentage of power loss throughout the test, by the formula: FI (%) = (PP − MP)/PP * 100. Furthermore, relative values were calculated by dividing absolutes values by kilograms of body mass (rPP and rXP), lean mass (rPP.LM and rXP.LM) or muscle mass (rPP.MM and rXP.MM). Participants were asked to refrain from strenuous physical activity 24 h before the all-out tests. Tests were randomly assigned to avoid sequencing bias.

Wingate test

It consisted of 30 s of riding at maximum speed performed using a Monark 894E cycle ergometer (Monark, Vansbro, Sweden) with an applied frictional resistance of 7.5% of body mass for men and 6% for women (Bar-Or, 1987). Participants were asked to ride at 50–70 rpm at 1 kp (50–70 watts) for 10 min to warm up. Subsequently, they took a 5-min recovery interval.

Then, at the count of 3, 2, 1… Go! The participant started to ride as fast as possible. A fly-start protocol was used, with a 3-s initial acceleration phase before applying the resistance to begin the test. The researcher encouraged the participant verbally during the test. A 5-min recovery ride at a warm-up pace was set to calm down.

Repeated jumps test

This test consisted of maximum countermovement jumps in 30 s at maximum height. A countermovement jump is a vertical jump initiated in a standing position with both hands on the pelvis by a downward movement. In this jump, the participant rapidly flexes the knees and hips to approximately 90 degrees before explosively extending them to drive the body upward. Participants were previously instructed on the correct way to perform the jumps. For its evaluation, the Chronojump® contact platform (Chronojump Boscosystem, Barcelona, Spain) was used. The absolute power values of each jump were extracted from the Chronojump® software version 2.3. All participants performed 5 min of easy running, three sets of 10 forward jumps, three sets of five vertical jumps, and 5 min of easy running to warm up. Afterwards, a 5-min interval was established to rest and set the platform and software. On the count of 3, 2, 1… Go! The participant began to jump as high and as fast as possible. The researcher verbally encouraged the participant to maintain maximum intensity throughout the interval. After, they walk for 5 min to calm down.

Anaerobic squat test

The test consisted of performing loaded deep squats for 30 s at maximum effort. For the present study, the same test protocol published by Ponce-García et al. (2021) with 75% of the participant’s body mass was used. A standard Olympic lifting set from Xenios USA® (Xenios USA LLC, New York, NY, USA), consisting of a 20 kg bar, plates between 5 kg and 15 kg in increments of 5 kg, and fractional plates of 0.5 and 2.5 kg in increments of 0.5 kg, was used. The recording of barbell speed and power of the repetitions was determined with a Chronojump® linear encoder (Chronojump Boscosystem, Barcelona, Spain). Absolute power values for each repetition were extracted from the data provided by the Chronojump® version 2.3 software. Before each test, participants were weighed to determine the barbell load, rounded to the nearest 0.5 kg. They began the warm-up with 5 min of easy running, followed by ten repetitions with an empty barbell, two more sets of ten repetitions with the assigned percentage and ended with 5 min of easy running. Afterwards, a recovery interval of 5 min was set and used to configure the encoder and software. On the count of 3, 2, 1… "Go!" The participant began to work at maximum effort, trying to perform as many squats as possible and being verbally motivated by the researcher throughout the test. They were asked to walk for 5 min to recover.

Statistical analysis

Table 8 presents the BC descriptive data of the sample in mean values and standard deviations. The normality of the variables was analyzed using the Shapiro-Wilk test, and the homogeneity of variances using the Levene test. A logarithmic transformation was performed for those variables that did not comply with some of the above assumptions (TRFM and WBFM in males). The Student's t-test was used to compare the mean values of the groups. SPSS version 21.0 software (IBM Corp., Armonk, NY, USA) was used to perform the different analyses. The effect size measure for sex differences was determined using Cohen's d by calculating the difference in means between the two sexes and dividing the result by the pooled standard deviation. The magnitude of effect sizes was interpreted; $d < 0.2$ was considered no effect, $0.2 \leq d < 0.5$ was considered a 'small' effect size, $0.5 \leq d < 0.8$ represented a 'medium' effect size, and $d \geq 0.8$ was considered a 'large' effect size (Cohen, 1988). The significance level was set at $p < 0.05$. In addition, differences between males and females were calculated as percentages through the following formula: %-dif = (MV − FV)/MV * 100, where MV corresponds to male values and FV to female values. Positive percentage values mean higher in men and negative percentage values mean higher in women.

Table 8. Descriptive data of the variables, gender comparison and effect size.

	Group (n=50)			**Male (n=25)**			**Female (n=25)**				
	Mean	**SD**	**SEM**	**Mean**	**SD**	**SEM**	**Mean**	**SD**	**SEM**	**t**	***d***
Age (years)	33.26	6.81	0.96	33.32	5.84	1.17	33.20	7.78	1.56	0.951	0.02
Body Mass (kg)	72.57	12.17	1.72	82.76	7.47	1.49	62.37	5.50	1.10	0.000	3.11
Height (cm)	169.55	8.71	1.23	176.90	4.16	0.83	162.20	5.01	1.00	0.000	3.20
BMI (kg·m^{-2})	25.06	2.31	0.33	26.43	2.03	0.41	23.70	1.70	0.34	0.000	1.46
LM (kg)	58.20	12.15	1.72	69.01	6.15	1.23	47.39	4.46	0.89	0.000	4.02
FM (kg)	15.49	3.14	0.44	15.15	3.25	0.65	15.82	3.05	0.61	0.459	0.21
FMP (%)	21.45	4.95	0.70	17.95	3.09	0.62	24.96	3.86	0.77	0.000	2.01
SMM (kg)	34.32	7.59	1.07	41.08	3.73	0.75	27.55	2.88	0.58	0.000	4.06

SD: standard deviation; SEM: standard error of the mean; t: significance of t-student analysis; *d*: Cohen d effect size; BMI: body mass index; LM: whole body lean mass in kg; FM: whole body fat mass in kg; FMP: whole body fat mass as percentage; SMM: skeletal muscle mass in kg; %-dif: percentage of difference

RESULTS

Table S1 (APPENDIX 10) shows absolute power values, adjusted for body mass, lean mass, muscle mass and fatigue index from each test. T-test results, effect sizes (d) and percentages of differences between sexes are also shown. Differences are graphically represented in Figure 18.

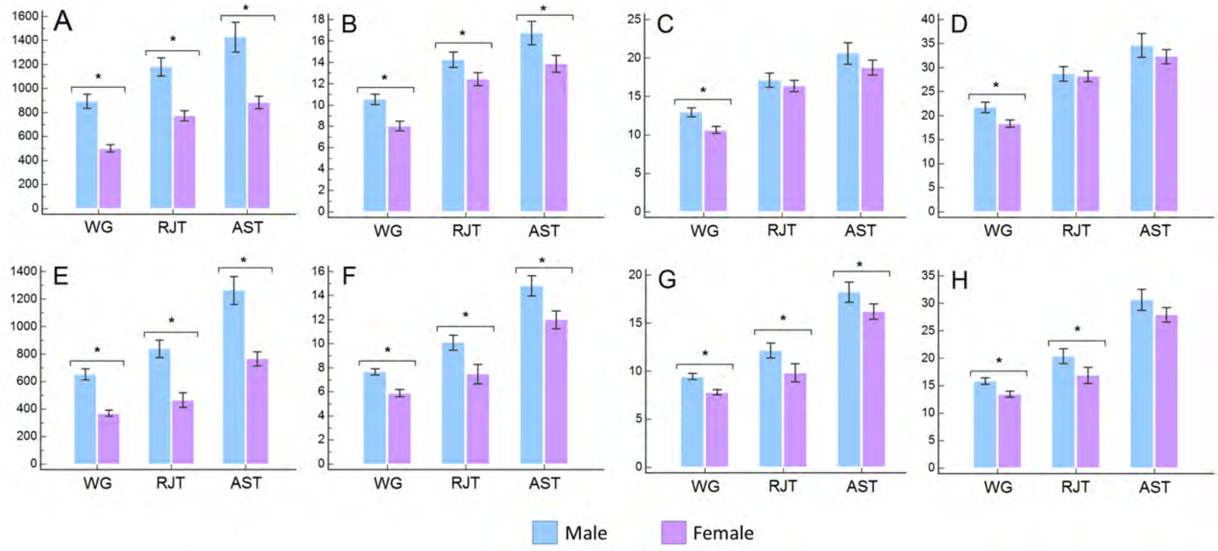

Figure 18. Comparison between sexes of peak and mean absolute and relative powers. WG, Wingate test; RJT, repeated jump test; AST, anaerobic squat test; (A) absolute peak power in watts (W); (B) peak power relative to body mass in watts per kg (W/kg); (C) peak power relative to lean mass in watts per kg (W/kgLM); (D) peak power relative to muscle mass in watts per kg (W/kgMM); (E) absolute mean power in watts (W); (F) mean power relative to body mass in watts per kg (W/kg); (G) mean power relative to lean mass in watts per kg (W/kgLM); (H) mean power relative to muscle mass in watts per kg (W/kgMM); *significant differences at $p < 0.05$ level.

Peak power

Significant differences were observed in all absolute variables (PP) and those adjusted for body mass (rPP) across all three tests (p < 0.01). When adjusting for lean mass (rPP.LM), significant differences were noted in the WG test (p < 0.01), whereas the RJT (p = 0.186) and AST (p = 0.059) tests did not show significant differences. In muscle mass-adjusted values (rPP.MM), WG also demonstrated significant differences (p < 0.01), while RJT (p = 0.565) and AST (p = 0.206) did not.

Regarding percentage differences, the absolute WG values showed a difference of 43.4% for PP. This percentage decreased to 23.6%, 17.5%, and 15.6% when adjusted for body, lean, and muscle mass, respectively. Notably, all percentage differences were higher in males compared to females.

For the RJT, the absolute percentage difference was 34.6%. When adjusted for body, lean, and muscle mass, the differences were 12.7%, 4.4%, and 1.8%, respectively, with higher values observed in males.

In the AST test, the absolute percentage difference was 36.9%. After adjusting for body mass, this difference was reduced to 16.1%. Further adjustments for lean and muscle mass decreased the differences to 7.6% and 5.6%, respectively, with all percentage differences again being higher in males.

Mean power

Significant differences were observed in all absolute variables (XP), body mass-adjusted variables (rXP), and those related to lean mass (rXP.LM), including WG, RJT and AST ($p < 0.01$). Specifically, WG, RJT, and AST showed significant differences concerning lean mass (WG: $p < 0.01$; RJT: $p < 0.01$; AST: $p = 0.015$). However, when adjusted for muscle mass (rXP.MM), only WG ($p < 0.01$) and RJT ($p < 0.01$) exhibited significant differences, while no significant differences were found for AST ($p = 0.057$).

The percentage differences in absolute values for WG were 43.3%. After adjusting for body, lean, and muscle mass, these differences decreased to 23.6%, 17.5%, and 15.4%, respectively. For the RJT, the absolute percentage differences were 44.6%, which reduced to 25.9%, 19.2%, and 17.3% after adjusting for body, lean, and muscle mass, respectively. In the AST, the absolute percentage difference was 37.8%, which decreased to 17.5%, 9.3%, and 7.3% when adjusted for body, lean, and muscle mass. Notably, all percentage values were higher in men.

Fatigue index

The only test that demonstrated significant differences between men and women in the FI was the RJT ($p < 0.01$). No significant differences were observed for the WG ($p = 0.235$) and the AST ($p = 0.067$). In percentage terms, men experienced 6.2% more fatigue in the WG than women. Conversely, women exhibited more significant fatigue than men in the RJT (17.5%) and AST (17.2%).

DISCUSSION

The main purpose of the present study was to determine whether there are significant differences between sexes in anaerobic performance in CF athletes in different maximal effort tests.

Peak power

Regarding the absolute peak powers (PP), the present study's results showed that male athletes exhibited higher values than females, and statistically significant differences were found in all the tests performed (WG, RJT, and AST). The findings are in line with those found by many authors in different populations like untrained university students (Mayhew & Salm, 1990), recreative active adults (Weber et al., 2006), team sport athletes (Soydan et al., 2018), wrestlers (Hübner-Woźniak et al., 2004), alpine ski racers (Miura, 2015), swimmers (Zera et al., 2022) and sprint cyclists (Ferguson et al., 2023). Moreover, measured in various tests of different nature like cycling (Ferguson et al., 2023; Zera et al., 2022), repeated sprint test (Hübner-Woźniak et al., 2004; Miura, 2015; Soydan et al., 2018), vertical jump (Mayhew & Salm, 1990) and other sports gestures (Mayhew & Salm, 1990; Zera et al., 2022). Although the results have been widely reported by other studies, using absolute values to compare performance between sexes is not the most appropriate due to the morphological and physiological differences and many other factors between men and women that should be considered. Therefore, the absolute values should be normalized or scaled for an optimal comparison between sexes.

In peak power relative to body mass (rPP), like absolute values, men showed higher relative values than women and significant differences in all tests performed (WG, RJT and AST). These differences have also been reported (Hübner-Woźniak et al., 2004; Vardar et al., 2007). Our study's reduction in differences between sexes agrees with other authors who showed similar results in wrestlers (Hübner-Woźniak et al., 2004; Vardar et al., 2007). These data suggest that adjusting absolute power relative to body mass might be an optimal way to standardize these values. However, it does not consider body composition since different lean or fat mass could show notable differences in relative values in subjects with the same body mass. Thus, significant differences in relative values could suggest that these differences may be related to quality rather than quantity of body mass (Maciejczyk et al., 2015).

When values were adjusted to lean mass (rPP.LM), men also showed higher values than women. However, significant differences were only found in WG but not in RJT or AST. Other authors previously reported this further reduction in differences (Hübner-Woźniak et al., 2004). These results might suggest that peak power is not determined by sex but by other variables, such as body composition (Maciejczyk et al., 2015) or specific tasks.

Relative powers to muscle mass (rPP.MM) likewise showed higher values in men. However, similar to adjusted powers to lean mass, significant differences were only found in WG, not RJT or AST. An additional reduction in the differences between sexes suggests that muscle mass and not lean mass determine peak power. This might be because lean mass includes physiologically non-active tissues such as bone and viscera. Additionally, a significant difference in WG might reveal that men and women use energy substrates or metabolic pathways differently when cycling or due to fibre type distribution or muscle activation differences (Driss & Vandewalle, 2013). The reduction of differences to negligible values, especially in jump and squat tests, again shows that anaerobic power depends on specific exercises and the amount of muscle mass rather than sex.

In percentage terms, the differences in absolute values (PP) between sexes were 43.4% in WG, 34.6% in RJT and 36.9% in AST. However, adjusting values for body mass (rPP) reduced the differences to 23.6% in WG, 12.7% in RJT and 16.1% in AST. This reduction in disparities has been reported previously in other athletes (Hübner-Woźniak et al., 2004). Adjusted values to lean mass (rPP.LM) further reduced differences to 17.5% for WG, 4.4% for RJT and 7.6% for AST. Lastly, relating values to muscle mass (rPP.MM) further reduced the differences to 15.6%, 1.8% and 5.6% in WG, RJT and AST, respectively. The reductions in differences found in values adjusted for body, lean and muscle mass suggest that peak power is determined mainly by muscle mass quantity. However, those differences differ depending on the assessed sporting gesture.

These results show that men have higher absolute and relative peak power values in all tests, regardless of BC. The decrease in differences with the adjustment of the values to lean mass or muscle mass indicates that sex is not as determining as these variables in anaerobic power in CF athletes. Likewise, these differences vary in the different assessed tasks.

Mean power

The absolute mean power values (XP) were higher in male athletes. They showed significant differences between sexes in all tests, as previously reported by Soydan et al. (2018), Hübner-Woźniak et al. (2004), and Zera et al. (2022). Like in peak powers, other physiological or morphological factors may determine differences in absolute values.

In mean powers related to body mass (rXP), values were higher in men, and their differences remained significant in all tests. However, the adjustment reduced differences between the sexes. This reduction has been previously published by other authors (Hübner-Woźniak et al., 2004). However, adjusting absolute power values to body mass may not be appropriate since it does not consider other variables, such as body composition, that could be directly related to the ability to produce greater power or sustain maximum effort for longer.

Values relative to lean mass (rXP.LM) continued to be higher in men, and significant differences in all tests were still present, similar to those reported in previous studies (Hübner-Woźniak et al., 2004). Furthermore, after eliminating body fat, persistent differences between groups may suggest that physiological issues such as better use of glycolytic metabolic pathways by male athletes may determine differences between sexes (Esbjörnsson et al., 1993).

Adjusted values to muscle mass (rXP.MM) were still higher in males but showed significant differences in WG and RJT, not in AST. These results may indicate that the ability to sustain maximal effort could be directly related to the contractile or metabolic properties of skeletal muscle, the higher proportion of type II fibres, and the greater capacity to regenerate ATP anaerobically in men (Esbjörnsson et al., 1993). Likewise, kinematic differences between sexes may determine the differences in power values adjusted to muscle mass in RJT (Kernozek et al., 2008; Pappas et al., 2007).

In percentages, the difference between male and female athletes in absolute values (XP) was 43.3% in WG, 44.6% in RJT and 37.8% in AST. When values were related to body mass (rXP), those differences were reduced to 23.6%, 25.9%, and 17.5% in WG, RJT and AST, respectively. Subsequently, a more significant reduction occurred when values were adjusted for lean mass (rXP.LM): 17.5% in WG, 19.2% in RJT, and 9.3% in AST. Finally, relating values to muscle mass (rXP.MM) further reduced the differences to 15.4% in WG, 17.3% in RJT, and 7.3% in AST.

These results show that men exhibit higher mean absolute and relative power values in all tests. The differences observed in all tests, except the muscle mass-adjusted values in AST, suggest that the ability to sustain a maximum effort differs between sexes, possibly due to metabolic factors in WG or kinematics in RJT.

Fatigue index

Concerning FI, our results showed statistically significant differences in RJT but not in WG or AST. The differences found in RJT could be attributable to biomechanical or neuromuscular factors (Kernozek et al., 2008; Márquez et al., 2017; McMahon et al., 2017; Pappas et al., 2007). In contrast, no such differences were found in WG or AST. Similar fatigue indices between sexes have been previously reported by other authors in team athletes in a repeated sprint test (Soydan et al., 2018).

Another notable finding is that men showed 6.2% more fatigue in the WG than women. However, females exhibited more fatigue in the RJT and AST than males, 17.5% and 17.2%, respectively. These data suggest that fatigue might depend on the task's specific demands (Hübner-Woźniak et al., 2004; Kernozek et al., 2008; Pappas et al., 2007; Pappas & Carpes, 2012).

We would like to highlight some of the present study's strengths. First, the sample size is considerably larger than the average of studies in this field. Second, the study compares three different tests based on different sports actions. This makes the applicability of the results of this study more comprehensive, especially in field-based tests, which offer sports professionals tools for immediate application to CF athletes.

Some limitations can be recognized in the present study. For example, gas exchange records for all tests are not available to determine whether differences in fatigability might be related to anaerobic metabolism, kinematic data that might be related to differences in performance in the different anaerobic tests, or data related to the participants' menstrual cycles that might affect the performance of the female athletes.

CONCLUSIONS

In conclusion, the results of this study indicate that the differences between sexes in absolute and relative peak and mean powers, as well as the amount of lean mass and muscle mass, explain power outputs assessed in both laboratory and field tests. The reduction of these differences in the values relative to lean and muscle mass suggests that anaerobic performance depends more on the amount of muscle mass. From this, training programs designed to increase lean muscle mass might benefit, to some extent, anaerobic performance in CF athletes, particularly in female athletes. However, further research is needed to understand better body mass and optimal lean and muscle mass levels that enhance anaerobic performance without detriment to the athletes' other abilities.

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IV. LIMITATIONS

"The enemy of art is the absence of limitations."

Orson Welles,

LIMITATIONS

In addition to those items specifically described in each of the publications that compound this thesis, the following limitations are also included:

Throughout the development process of this thesis, controversy and disparity of opinions have arisen among authors regarding the validity of the instrument used to measure the powers in Article 1 (the Beast sensor). At the time of data collection, we were unaware of these differences; therefore, we were guided by the study published at the time (referenced in that paper), which showed the instrument to be reliable and valid. The use of tools of proven reliability and validity is suggested for possible replication of the study presented in this thesis.

Another limitation to highlight is the exclusion of other performance tests, such as any from competition or official WODs, which prevents relating them to the anaerobic laboratory (WG) or field tests performed in this work. Determining their association might provide crucial data for practical applications by coaches and sports professionals.

V. CONCLUSIONS

“What you get when you achieve your goals is not
as important as what you become.”

Henry David Thoreau.

CONCLUSIONS

Article 1

- Although the level of agreement between the four methods and the WG is good, the results show that they cannot be used interchangeably to analyse anaerobic fitness in CF athletes due to the systematic error found between methods. As well as the proportional error found in ABT.

Article 2

- LM and total and segmental body fat percentage are moderate to very high associated with anaerobic fitness in CF athletes.

- The prediction models developed in this study show that total and segmental LM values are strong predictors of power and anaerobic capacity, as determined in the Wingate test.

Article 3

- There are significant differences between sexes in absolute peak and mean power outputs. However, differences are reduced when values for body mass, lean mass and muscle mass are adjusted. These results suggest that anaerobic fitness is more dependent on the amount of MM than on sex.

- The differences between sexes in our study regarding power and FI values in the tests suggest that anaerobic performance and fatigue values might be task-dependent.

APPENDIX 1

Research paper 1 in its original journal format

International Journal of
*Environmental Research
and Public Health*

MDPI

Article

The Anaerobic Power Assessment in CrossFit® Athletes: An Agreement Study

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Abstract: Anaerobic power and capacity are considered determinants of performance and are usually assessed in athletes as a part of their physical capacities' evaluation along the season. For that purpose, many field tests have been created. The main objective of this study was to analyze the agreement between four field tests and a laboratory test. Nineteen CrossFit® (CF) athletes were recruited for this study (28.63 ± 6.62 years) who had been practicing CF for at least one year. Tests performed were: (1) Anaerobic Squat Test at 60% of bodyweight (AST60); (2) Anaerobic Squat Test at 70% of bodyweight (AST70); (3) Repeated Jump Test (RJT); (4) Assault Bike Test (ABT); and (5) Wingate Anaerobic Test on a cycle ergometer (WG). All tests consisted of 30 s of max effort. The differences among methods were tested using a repeated-measures analysis of variance (ANOVA) and effect size. Agreement between methods was performed using Bland–Altman analysis. Analysis of agreement showed systematic bias in all field test PP values, which varied between −110.05 ($AST60_{PP}$—WG_{PP}) and 463.58 (ABT_{PP}—WG_{PP}), and a significant proportional error in ABT_{PP} by rank correlation ($p < 0.001$). Repeated-measures ANOVA showed significant differences among PP values ($F(1.76,31.59) = 130.61$, $p =< 0.001$). In conclusion, since to our knowledge, this is the first study to analyze the agreement between various methods to estimate anaerobic power in CF athletes. Apart from ABT, all tests showed good agreement and can be used interchangeably in CF athletes. Our results suggest that AST and RJT are good alternatives for measuring the anaerobic power in CF athletes when access to a laboratory is not possible.

Keywords: anaerobic power; peak power; HIFT, high-intensity functional training; crossfit; athletes; field test

check for updates

Citation: Ponce-García, T.; Benítez-Porres, J.; García-Romero, J.C.; Castillo-Domínguez, A.; Alvero-Cruz, J.R. The Anaerobic Power Assessment in CrossFit® Athletes: An Agreement Study. *Int. J. Environ. Res. Public Health* **2021**, *18*, 8878. https://doi.org/10.3390/ijerph18168878

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1. Introduction

Anaerobic capacity has been defined as the total amount of ATP re-synthesized, by the whole body, during a maximal intensity and short duration effort by means of the anaerobic metabolic pathways [1]. The time interval to best measure the anaerobic capacity is 30 s [2] since up to 80% of the energy consumed in 30 s of maximal effort comes from anaerobic sources [3,4]. In addition, in a longer test, individuals tend not to apply the maximum intensity [5]. There are several laboratory tests to assess the anaerobic performance [6]. However, most are expensive and difficult to perform due to the specific equipment they require. For that reason, one of the most widely used laboratory tests to assess this ability is the Wingate test, which consists of pedaling with arms or legs at maximum effort for 30 s against a resistance determined by the participant's body weight. WG has shown to be a reliable test, having a test-retest correlation in many populations ranging from 0.89 to 0.98 [7]. Two main variables are determined from this test, peak power (PP) and mean power (XP). PP is also known as "anaerobic power" and is determined by the peak mechanical power recorded during the test, normally occurring in the first 5 to 10 s. In addition, XP is considered by many authors as the "anaerobic capacity" and represents

APPENDIX 2

Research paper 2 in its original journal format

2025, Retos, 62, 543-552

The association of Whole and Segmental Body Composition and Anaerobic Performance in Crossfit® athletes: sex differences and performance prediction

Asociación entre la composición corporal total y segmentaria y el rendimiento anaeróbico en atletas de Crossfit®: diferencias entre sexos y predicción del rendimiento

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Abstract. The main purpose of this study was to establish the association between total and segmental body composition (BC) variables and anaerobic performance and to create optimal models that best predict such performance in CrossFit® (CF) athletes. Fifty athletes, 25 males and 25 females (age: 33.26 ± 6.81 years; body mass: 72.57 ± 12.17 kg; height: 169.55 ± 8.71 cm; BMI: 25.06 ± 2.31 kg·m−2) were recruited to participate and underwent BC analysis using dual-energy X-ray absorptiometry (DXA) and an all-out laboratory test on a cycle ergometer (Wingate) to determine their anaerobic performance. The results show a significant correlation between BC values and performance, ranging from moderate ($r = -0.34$, $p = 0.015$) to near-perfect ($r = 0.96$, $p < 0.01$). Furthermore, the created performance prediction models exhibited predictive capacities ranging from 19% ($p = 0.017$) to 93% ($p < 0.001$). All prediction models were created using total or segmental lean mass variables, excluding others. The studied body composition and performance variables found significant differences between males and females. The findings demonstrate that body composition variables are crucial indicators of anaerobic performance in CF athletes. In this regard, it may be advisable for sports performance professionals to consider this information when monitoring athletes throughout the season or designing specific training programs. Similarly, the use of predictive equations could be a useful tool for estimating peak and mean power values.
Keywords: sports performance, anaerobic performance, body composition, athletes, CrossFit®, high-intensity functional training

Resumen. El objetivo principal del presente estudio fue establecer la asociación entre las variables de composición corporal (CC) total y segmentaria y el rendimiento anaeróbico, así como crear los modelos de regresión que mejor predigan dicho rendimiento en atletas de CrossFit® (CF). Cincuenta atletas, 25 hombres y 25 mujeres (edad: 33,26 ± 6,81 años; masa corporal: 72,57 ± 12,17 kg; estatura: 169,55 ± 8,71 cm; IMC: 25,06 ± 2,31 kg-m^{-2}) fueron reclutados para participar y se sometieron a un análisis de la CC mediante absorciometría de rayos X de energía dual (DXA) y a una prueba de laboratorio a máximo esfuerzo en un cicloergómetro (Wingate) para determinar su rendimiento anaeróbico. Los resultados muestran una correlación significativa entre los valores de CC y el rendimiento, que va de moderada ($r = -0{,}34$, $p = 0{,}015$) a casi perfecta ($r = 0{,}96$, $p < 0{,}01$). Además, los modelos de predicción del rendimiento creados mostraron capacidades predictivas que oscilaron entre el 19% ($p = 0{,}017$) y el 93% ($p < 0{,}001$). Todos los modelos de predicción se crearon utilizando variables de masa magra total o segmentaria, excluyendo otras. Las variables de composición corporal y rendimiento estudiadas encontraron diferencias significativas entre hombres y mujeres. Los resultados demuestran que las variables de composición corporal son indicadores cruciales del rendimiento anaeróbico en atletas de CF. En este sentido, sería recomendable que los profesionales responsables del rendimiento deportivo consideren esta información al momento de monitorizar a los atletas durante la temporada o al diseñar programas de entrenamiento específicos. Del mismo modo, el uso de ecuaciones de predicción podría resultar útil como herramienta para estimar los valores de potencia máxima y media.
Palabras clave: rendimiento deportivo, rendimiento anaeróbico, composición corporal, atletas, CrossFit®, entrenamiento funcional de alta intensidad.

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Introduction

Body composition (BC) refers to the ratio of the different components of the human body. One of the most widely used body composition models in research is the 2-compartment model. It divides the body into two main components: fat mass and fat-free mass, also known as Lean Body Mass (LBM), which includes everything that is not fat in the body, such as muscle, bone, organs, and water. Instead, fat mass refers to the amount of adipose tissue in the body. The proportion of each of these components varies according to an individual's age, gender, ethnicity, and physical activity level (Guo S et al., 1999; Kirchengast, 2010; Wulan et al., 2010). BC can be studied in total values (of the whole body) or segmentally (by regions). Segmental BC measures body composition, dividing the body into various anatomical regions, such as the arms, legs, trunk, and head. Segmental BC provides detailed information on body mass distribution and can help assess body asymmetry. The applications of BC are diverse and range from health evaluation to the design of personalized training and nutrition programs. Therefore, accurate measurement of BC can provide valuable information about health, fitness, and sports performance.

In sports, some BC components are used as a selection method, monitoring throughout the year, and predicting athletes' performance (Rudnev, 2020). In addition, athletes and coaches are aware of the importance of BC in sports performance and injury prevention (Lukaski & Raymond-Pope, 2021) since BC can significantly affect athletic performance by influencing an athlete's strength, power (Ben Mansour et al., 2021) and agility. Some authors have studied the relationship between some of the components of BC and performance in different physical tests in athletes (Corredor-Serrano et al., 2023; García-Chaves et al., 2023; Kim et al., 2011; Pearson et al., 2019). For example, excess fat mass has been shown to have a negative impact on physical performance (Lockie et al., 2021; Mangine et al.,

APPENDIX 3

Research paper 3 in its original journal format

Sex differences in anaerobic performance in CrossFit® athletes: a comparison of three different all-out tests

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ABSTRACT

Background: Athletic performance can be influenced by various factors, including those related to biological sex. Various scientific disciplines have studied the observed differences in athletic performance between men and women. Moreover, anaerobic performance refers to the capacity of the human body to generate energy quickly and efficiently during high-intensity and short-duration activities. It is associated with the ability to perform explosive actions and the capacity for rapid recovery between repeated efforts. Anaerobic performance is a determining factor for performance in high-intensity sports and those with predominantly lower intensity but intermittent peaks of higher intensity. One high-intensity sport that has experienced exponential growth and attracts increasing numbers of participants yearly is commercially known as CrossFit® (CF). Therefore, the primary purpose of this study was to determine the anaerobic performance differences between sexes in CF athletes in terms of absolute and relative values.

Methods: A cross-sectional study was conducted over 2 weeks. Fifty CrossFit® athletes (25 men and 25 women) voluntarily participated in the study. They were subjected to body composition analysis and three maximal effort tests to measure anaerobic performance: a cycle ergometer test, a continuous jump test and a squat test.

Results: Significant differences were found in all the variables of absolute peak power and relative to body mass in the three tests. In values adjusted to lean and muscle mass, significant differences were only found in the cycle ergometer test but not in the other two. In mean power variables, significant differences were found in all the variables studied, except for the mean power adjusted to muscle mass in the squat test. In conclusion, this study's results indicate that differences between sexes in absolute and relative peak powers measured in all tests evaluated are explained by the amount of lean and muscle mass. However, mean powers show significant differences in all variables except for the one related to muscle mass in the squat test.

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APPENDIX 4

Poster communication presented in October 2020
at the 25th Virtual Congress of the ECSS.
European College of Sport Science.
Online.

THE ANAEROBIC SQUAT TEST AS A VALID AND RELIABLE ALTERNATIVE TO MEASURE THE ANAEROBIC CAPACITY IN HIGH INTENSITY FUNCTIONAL TRAINING ATHLETES.

Ponce-García, T., Alvero-Cruz, J.R., García-Romero, J., Benítez-Porres, J.

INTRODUCTION: different tests have been proposed to quantify the anaerobic capacity in trained individuals (Čular et al., 2018; Fry et al., 2014; Sands et al., 2004). However, most of them are difficult to apply due to their complexity or equipment/facilities requirement. The Anaerobic Squat Test (AST) is a 30 seconds maximal effort test where athletes has to perform as many squats as possible with a percentage of their body weight. The purpose of this study was to validate an affordable cost-economic tool in order to evaluate the anaerobic capacity in athletes. **METHODS:** nineteen High Intensity Functional Training (HIFT) athletes were recruited (age 28.3 ± 6.62 years; stature 176.18 ± 5.34 cm; weight 81.67 ± 6.43 kg) and tested on separate sessions with 48 hours of difference. They were advised to refrain from any high intensity physical activity the previous 24 hours of every test. Two different percentages of intensity were carried out: 60% (AST60) and 70% (AST70) as percentage of body weight. Power values were registered by accelerometry (Beast Sensor) and Wingate test as a reference. Reliability was assessed by intra-class correlation coefficients (ICC) and validity by Pearson correlation coefficients for peak (pp), mean (xp) and minimum (mp) power outputs compared with Wingate test (WG). **RESULTS:** peak power values of AST60 and AST70 showed significant correlation with WG (AST60_{PP} $r = 0.51$, $p < 0.05$ and AST70_{PP} $r = 0.55$, $p < 0.05$). Regarding to mean power, only AST60 showed significant correlation with WG (AST60_{xp} $r = 0.49$, $p < 0.05$). No statistically significant correlations were found in minimal power values. The ICCs of AST60 peak, mean and minimum power were 0.64 (95% CI: 0.22-0.86), 0.76 (95% CI: 0.45-0.91) and 0.71 (95% CI: 0.33-0.89), respectively. Values for AST70 were 0.61 (95% CI: 0.19-0.84), 0.67 (96% CI: 0.30-0.87) and 0.71 (95% CI: 0.35-0.88), respectively. **CONCLUSION:** in conclusion, our results suggest that the AST is a valid and reliable tool to measure the anaerobic capacity in HIFT athletes. Further prospective studies using higher intensity percentages (e.g., 75% or 80%) are needed in order to find more accurate agreement.

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25TH ANNIVERSARY CONGRESS
OCTOBER 28-30, 2020

The Anaerobic Squat Test as a valid and reliable alternative to measure the anaerobic capacity in High Intensity Functional Training Athletes

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Introduction

Different tests have been proposed to quantify the anaerobic capacity and power in trained individuals (Cular et al., 2018; Fry et al., 2014; Sands et al., 2004) However, most of them are difficult to apply due to the complexity or equipment/facilities requirement.

The Anaerobic Squat Test (AST) (Figure 1, right) is a 30 seconds maximal effort test where athletes had to perform as many squats as possible with a percentage of their body weight.

The purpose of this study was to compare two anaerobic test to validate an affordable cost-economic tool in order to evaluate the anaerobic capacity in athletes.

Methods

Nineteen High Intensity Functional Training (HIFT) athletes were recruited (age 28.3 ± 6.62 years; stature 176.18 ± 5.34 cm; weight 81.67 ± 6.43 kg) and tested on separate sessions with 48 hours of difference.

They were advised to refrain from any high intensity physical activity the previous 24 hours of every test. Two different percentages of intensity were carried out: 60% (AST60) and 70% (AST70) as percentage of body weight.

Power values were registered by accelerometry (Beast Sensor) and Wingate test as a reference. Reliability was assessed by intra-class correlation coefficients (ICC) and validity by Pearson correlation coefficients for peak (PM), mean (PX) and minimum (Pmin) power outputs compared with Wingate test (WG) (Figure 1, left).

Figure 1. Tests performance: Wingate (left) at the lab and AST (right) at the sport center.

Results

Peak power values of AST60 and AST70 showed significant correlation with WG (AST60PM r = 0.65, $p < 0.05$ and AST70PM r = 0.72, $p < 0.05$).

Regarding to mean power, both AST showed significant correlation with WG (AST60PX r = 0.77, $p < 0.05$ and AST70PX r=0.75. $p< 0.05$).

Moreover statistically significant correlations were found in minimal power values (AST60Pmin r = 0.85, $p < 0.0001$ and AST70Pmin r=0.68. $p< 0.05$).

The ICCs of AST60 peak, mean and minimum power were 0.79 (95% CI: 0.42-0.92), 0.86 (95% CI: 0.60-0.95) and 0.91 (95% CI: 0.74-0.97), respectively. Values for AST70 were 0.84 (95% CI: 0.56-0.94), 0.80 (95% CI: 0.46-0.92) and 0.85 (95% CI: 0.61-0.94), respectively.

Table 1. Measurements of reliability and validity of the test

Test	Reliability		Validity	
	ICC	95% CI	r	P
WG PM	0.9745	0.9239 to 0.9914	0.954	<0.0001
WG PX	0.9122	0.7384 to 0.9705	0.844	0.0001
WG PMIN	0.7735	0.3253 to 0.9240	0.635	0.011
TAS 60 PM	0.7906	0.4219 to 0.9242	0.654	0.0044
TAS 60 PX	0.8564	0.6034 to 0.9480	0.767	0.0003
TAS 60 PMIN	0.9065	0.7419 to 0.9662	0.852	<0.0001
TAS 70 PM	0.8367	0.5635 to 0.9389	0.72	0.0007
TAS 70 PX	0.7979	0.4596 to 0.9244	0.748	0.0004
TAS 70 PMIN	0.8525	0.6057 to 0.9448	0.683	0.0018

WG PM: Wingate peak power; WG PX: Wingate mean power; WG PMIN: Wingate mínimum power; TAS 60 PM: AST60 peak power; TAS 60 PX: AST60 mean power; TAS 60 PMIN: AST60 minimum power; TAS 70 PM: AST70 peak power; TAS 70 PX: AST70 mean power; TAS 70 PMIN: AST70 minimum power; ICC: Intraclass correlation coeficient; CI: Confidence interval; r: Pearson correlation coeficient.

Discussion & Conclusion

Other authors have used the back squat to measure the anaerobic power showing reliabe and valid results (Fry et al, 2014), However, the anaerobic squat test (AST) to measure the anaerobic capacity applied in the present work has not been found in previous studies; therefore, the presented results cannot be compared to any other.

In conclusion, our results suggest that the AST is a valid and reliable tool to measure the anaerobic capacity in HIFT athletes. Further prospective studies using higher intensity percentages (e.g., 75% or 80%) are needed in order to find more accurate reliability and validity.

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APPENDIX 5

Poster communication presented in June 2021
At the 2021 Annual Meeting & World Congresses of ACSM
The American College of Sports Medicine
Online

BODY COMPOSITION AND ANAEROBIC CAPACITY IN HIGH INTENSITY FUNCTIONAL TRAINING ATHLETES.

Tomás Ponce-García, José R. Alvero-Cruz, Jerónimo García-Romero, Javier Benítez-Porres

Relationship between different components of body composition and individual characteristics in athletes has been partially studied. Nowadays, body composition is widely used as a method of athlete selection, fitness monitoring and performance prediction along the season. **PURPOSE:** To correlate body composition levels and anerobic performance in High Intensity Functional Training **(**HIFT) athletes and develop multiple regression models. **METHODS:** Nineteen male HIFT athletes participated in this study (Age 28.63 ± 6.62 year; Height 176.18 ± 5.34 cm; Bodyweight 81.67 ± 6.43 kg; BMI 26.29 ± 1.34). Fat mass (FM_{kg}), Lean Body Mass (LBM_{kg}), Muscle Mass (MM_{kg}) and Total Body Water (TBW_{kg}) expressed in kg were estimated by bioelectrical impedance analysis. Anaerobic capacity was tested by the gold standard Wingate test (WG), determining peak (WG_{PP}), mean (WG_{XP}) and minimal (WG_{MP}) power values. Pearson correlation coefficient was used to define the association between variables and stepwise multiple regression analysis to determine their relationship. The research protocol was reviewed and approved by the Ethics Committee of the University of Málaga (43-2018-H) **RESULTS:** LBM_{kg} showed significant correlation with WG_{PP} ($r = 0.75$, $p < 0.001$), WG_{XP} ($r = 0.85$, $p < 0.001$) and WG_{MP} ($r = 0.73$, $p < 0.001$). MM_{kg} also showed significant correlation with WG_{PP} ($r = 0.83$, $p < 0.001$), WG_{XP} ($r = 0.86$, $p < 0.001$) and WG_{MP} ($r = 0.66$, $p= 0.002$). The regression equation developed for peak power was: $WG_{PP} = -164.202 + 227.055 * MM_{kg}$, $R^2= 0.67$, SEE= 3.6915 W, $p < 0.001$. Two equations models were developed for mean power, one explained by lean body mass: $WG_{XP} = 313.1151 + 6.1724 * LBM_{kg}$, $R^2= 0.70$, SEE= 0.9417 W, $p < 0.001$; and the other by muscle mass: $WG_{XP} = 79.0879 + 16.7175 * MM_{kg}$, $R^2= 0.72$, SEE= 2.4469 W, $p < 0.001$. **CONCLUSION:** Results showed moderate-high correlation between some variables of body composition and anaerobic performance values. Moreover, we can conclude that LBM_{kg} and MM_{kg} are strong predictors of anaerobic capacity in HIFT athletes, explaining up to 70% of some of the anaerobic test values.

Body composition and anaerobic capacity in High Intensity Functional Training Athletes

Ponce-García, T., Alvero-Cruz, J.R., García-Romero, J.C., Benítez-Porres, J
Universidad de Málaga-Andalucía Tech
Dpto de Fisiología Humana, Histología, Anatomía Patológica y Educación Física y Deportiva

Abstract

Relationship between different components of body composition and individual characteristics in athletes has been partially studied. Nowadays, body composition is widely used as a method of athlete selection, fitness monitoring and performance prediction along the season. **PURPOSE:** To correlate body composition levels and anerobic performance in High Intensity Functional Training (HIFT) athletes and develop multiple regression models. **METHODS:** Nineteen male HIFT athletes participated in this study (Age 28.63 ± 6.62 year; Height 176.18 ± 5.34 cm; Bodyweight 81.67 ± 6.43 kg; BMI 26.29 ± 1.34). Fat mass (FM_{kg}), Lean Body Mass (LBM_{kg}), Muscle Mass (MM_{kg}) and Total Body Water (TBW_{kg}) expressed in kg were estimated by bioelectrical impedance analysis. Anaerobic capacity was tested by the gold standard Wingate test (WG), determining peak (WG_{PP}), mean (WG_{XP}) and minimal (WG_{MP}) power values. Pearson correlation coefficient was used to define the association between variables and stepwise multiple regression analysis to determine their relationship. The research protocol was reviewed and approved by the Ethics Committee of the University of Málaga (43-2018-H) **RESULTS:** LBM_{kg} showed significant correlation with WG_{PP} ($r = 0.75$, $p < 0.001$), WG_{XP} ($r = 0.85$, $p < 0.001$) and WG_{MP} ($r = 0.73$, $p < 0.001$). MM_{kg} also showed significant correlation with WG_{PP} ($r = 0.83$, $p < 0.001$), WG_{XP} ($r = 0.86$, $p < 0.001$) and WG_{MP} ($r = 0.66$, $p= 0.002$). The regression equation developed for peak power was: $WG_{PP} = -164.202 + 227.055 * MM_{kg}$, $R^2= 0.67$, SEE= 3.6915 W, $p < 0.001$. Two equations models were developed for mean power, one explained by lean body mass: $WG_{XP} = 313.1151 + 6.1724 * LBM_{kg}$, $R^2= 0.70$, SEE= 0.9417 W, $p < 0.001$; and the other by muscle mass: $WG_{XP} = 79.0879 + 16.7175 * MM_{kg}$, $R^2= 0.72$, SEE= 2.4469 W, $p < 0.001$. **CONCLUSION:** Results showed moderate-high correlation between some variables of body composition and anaerobic performance values. Moreover, we can conclude that LBM_{kg} and MM_{kg} are strong predictors of anaerobic capacity in HIFT athletes, explaining up to 70% of some of the anaerobic test values.

Introduction

Relationship between different components of body composition and individual characteristics in athletes has been partially studied. Nowadays, body composition is widely used as a method of athlete selection, fitness monitoring and performance prediction along the season (Rudnev, 2020). Many authors have studied the relationship between body composition and performance in different physical tests in athletes (Kim et al., 2011; Pearson et al., 2019). However, no studies have been found correlating body composition and anaerobic performance, in athletes who follow a high intensity functional training program (HIFT).

Therefore, the purpose of this study was to correlate body composition variables and anerobic performance in High Intensity Functional Training (HIFT) athletes and develop multiple regression models.

Figure 1. Wingate Test performed at the laboratory

Methods

Nineteen male HIFT athletes participated in this study (Age 28.63 ± 6.62 year; Height 176.18 ± 5.34 cm; Bodyweight 81.67 ± 6.43 kg; BMI 26.29 ± 1.34).

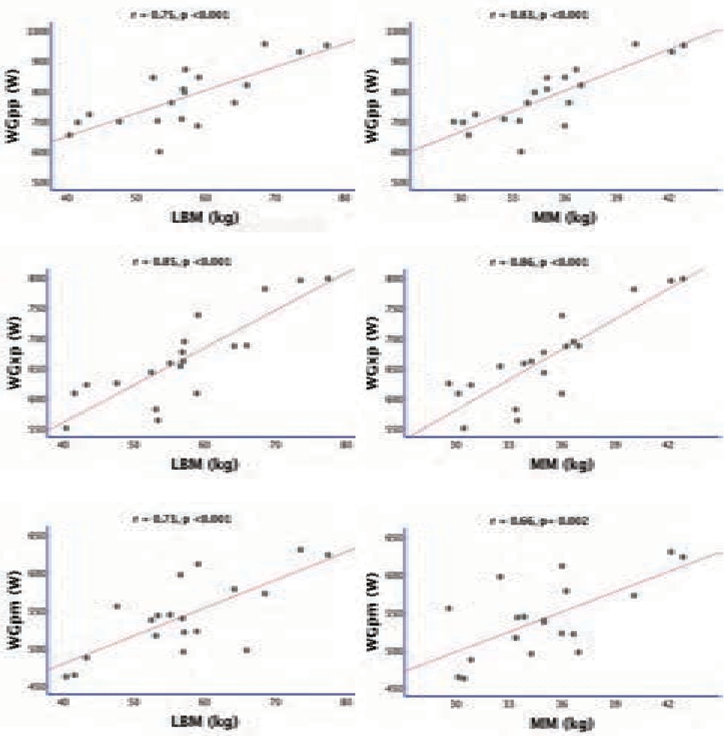
Fat mass (FMkg), Lean Body Mass (LBMkg) and Muscle Mass (MMkg) in kg were estimated by a Medisystem Multifrequency Impedancemeter (Sanocare Human System SL, Madrid, Spain). Participants were asked to refrain from consuming any drink or food for at least 4 hours, alcohol in the last 48 hours, diuretics in the last 7 days, or having performed any strenuous physical activity in the previous 12 hours (Cruz et al., 2010).

Anaerobic power and capacity was tested by the considered gold standard Wingate test (WG) with a Monark cycle ergometer, model 828E (Monark Exercise AB, Vansbro, Sweden), which was calibrated before each test (Figure 1).

Table 1. Multiple regression models

Dependent Variable	Independent Variable	Coeficient	SE	P	VIF	R^2	R^2-ajust.
WG_{PP}	Constant	-164,202				0,69	0,67
	MM_{kg}	227,055	3,6915	<0,001	1		
WG_{XP}	Constant	313,1151				0,72	0,70
	LBM_{kg}	6,1724	0,9417	<0,001	1		
	Constant	79,0879				0,73	0,72
	MM_{kg}	16,7175	2,4469	<0,001	1		
WG_{MP}	Constant	331,4452				0,54	0,51
	LBM_{kg}	3,6923	0,8288	<0,001	1		
	Constant	232,3747				0,43	0,40
	MM_{kg}	8,8320	2,4671	0,002	1		

WG_{PP}, peak power; WG_{XP}, mean power; WG_{MP}, minimal power; LBM_{kg}, lean body mass; MM_{kg}, muscle mass; VIF, variance inflation factor.



Results

LBM_{kg} showed significant correlation with WG_{PP} ($r = 0.75$, $p <0.001$), WG_{XP} ($r = 0.85$, $p <0.001$) and WG_{MP} ($r = 0.73$, $p <0.001$). MM_{kg} also showed significant correlation with WG_{PP} ($r = 0.83$, $p <0.001$), WG_{XP} ($r = 0.86$, $p <0.001$) and WG_{MP} ($r = 0.66$, $p= 0.002$).

One regression equation developed for peak power was developed and two equations models for mean power, one explained by lean body mass and the other by muscle mass. The results of the multiple regression analysis are shown in Table 1.

$$WG_{PP} = -164.202 + 227.055 * MM_{kg}$$

$$WG_{XP} = 313.1151 + 6.1724 * LBM_{kg}$$

$$WG_{XP} = 79.0879 + 16.7175 * MM_{kg}$$

Discussion & Conclusion

- Our findings agree with those found by (Sanders et al., (2018) in people with an average fitness, where the LBM of the trunk and lower limbs showed a positive correlation with anaerobic performance.
- Other authors have found high correlations between total LBM with peak and mean powers of the anaerobic test in baseball players (Pearson et al., 2019), as well as in physically active subjects in an all-out test of 20 seconds on a cycle ergometer (Maciejczyk et al., 2014).
- Our results show a high correlation between MM and LBM with anaerobic performance variables.
- LBM and MM, separately, are predictors of performance in the anaerobic capacity test, explaining around 70% of the total variance of peak power.

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APPENDIX 6

Oral communication presented in April 2022
At the 19th Annual Scientific Conference of Montenegrin Sports Academy:
'Sport, Physical Activity and Health: Contemporary perspectives',
in Cavtat, Dubrovnik, Croatia

RELATIONSHIP BETWEEN BODY COMPOSITION AND REPEATED JUMP PERFORMANCE IN CROSSFIT® ATHLETES.

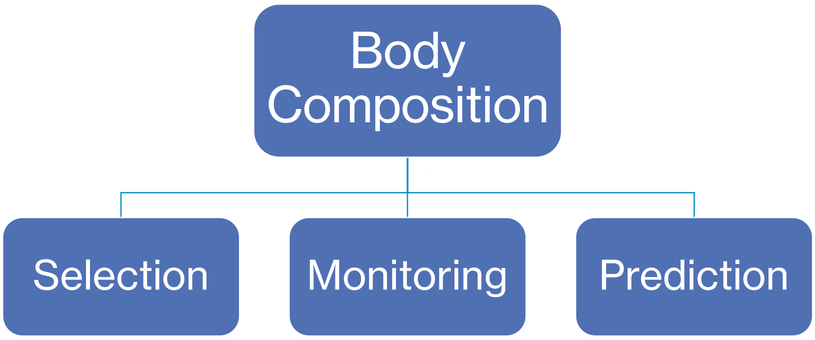
Tomás Ponce-García, José R. Alvero-Cruz, Jerónimo García-Romero, Javier Benítez-Porres

Association between body composition and athletes' performance has been frequently studied and used as a method of athlete selection, monitoring and performance prediction. **PURPOSE:** To correlate body composition and repeated jump performance in CrossFit® (CF) athletes and develop multiple regression models. **METHODS:** Nineteen male CF athletes participated in this study (Age 28.63±6.62 year; Height 176.18±5.34 cm; Bodyweight 81.67±6.43 kg; BMI 26.29±1.34). Fat mass (FMkg), Lean Body Mass (LBMkg) and Muscle Mass (MMkg) expressed in kg were estimated by bioelectrical impedance analysis. Repeated jump performance was tested by the 30 seconds repeated jump test (RJT). Peak (RJTPP), mean (RJTXP) and minimal (RJTMP) power values were determined. Pearson correlation coefficient was used to define the association between variables and stepwise multiple regression analysis to determine their relationship. **RESULTS:** LBMkg showed significant correlation with RJTPP ($r=0.78$, $p<0.001$), RJTXP ($r=0.80$, $p<0.001$) and RJTMP ($r=0.65$, $p=0.003$). MMkg also showed significant correlation with RJTPP ($r=0.87$, $p<0.001$), RJTXP ($r=0.88$, $p<0.001$) and RJTMP ($r=0.75$, $p<0.001$). Two regression equations for peak and mean power were developed: $RJTPP=330.438+22.602*MMkg$, $R^2=0.74$, SEE=3.1678W, $p<0.001$ and $RJTXP=237.1671+22.830*MMkg$, $R^2=0.75$, SEE=3.0434W, $p<0.001$. **CONCLUSION:** Results showed moderate-high correlation between some variables of body composition and power values. Moreover, we can conclude that MMkg is a strong predictor of repeated jump performance in CF athletes, explaining over 70% of some of the power values.

Relationship between body composition and repeated jump performance in CrossFit® Athletes

Tomás Ponce García

Introduction



Body Composition

Selection

Monitoring

Prediction

(Rudnev, 2020)

Introduction

Body composition has shown to be related to:

-LBM ↔ PP & XP (Wingate Test)

(Vardar et al., 2007; Perez-Gomez et al,, 2008; Maciejczyk et al,, 2015)

-LBM ↔ VO2max (Maciejczyk et al,, 2014)

Introduction

Vertical jump: (SJ, CMJ, RJT, etc.)

- -Neuromuscular perf.
- -Lower Limb power
- -Etc…

BC ↔ Jump

(Nikolaidis et al, 2016; Van Hooren, & Zolotarjova, 2017; Watkins et al,, 2017; Ishida et al,, 2021)

What about Crossfit® athletes?

Introduction

Purpose:

-To correlate BC with Repeated Jump performance in CF athletes

-Develop Multiple regression models

Methods

Participants:

-19 male CF Athletes:
   - -Age: 28.63 ± 6.62 year
   - -Height: 176.18 ± 5.34 cm
   - -Body mass: 81.67 ± 6.43 kg
   - -BMI 26.29: ± 1.34 kg/m^2

-One year experience
-No injuries or pathologies
-Informed Consent

Methods

Body Composition (BIA Inbody 770):

- Fat mass (FM_{kg})
- Lean Body Mass (LBM_{kg})
- Muscle Mass (MM_{kg})
- Total Body Water (TBW_L)

-Fasting or **NO** drinks or food for 4h
-**NO** Alcohol for 24h
-**NO** diuretics for a week

Methods

Repeated Jump Test (RJT)

-30 s CMJ at the maximum height (Dal Pupo et al,, 2014)

-Warm up:

5 min Run → 3 x 10 forward jumps → 3 x 5 vertical jumps → 5min Run → Rest → TEST

Peak (PP), Mean (XP) and minimal (MP) power were determined.

Methods

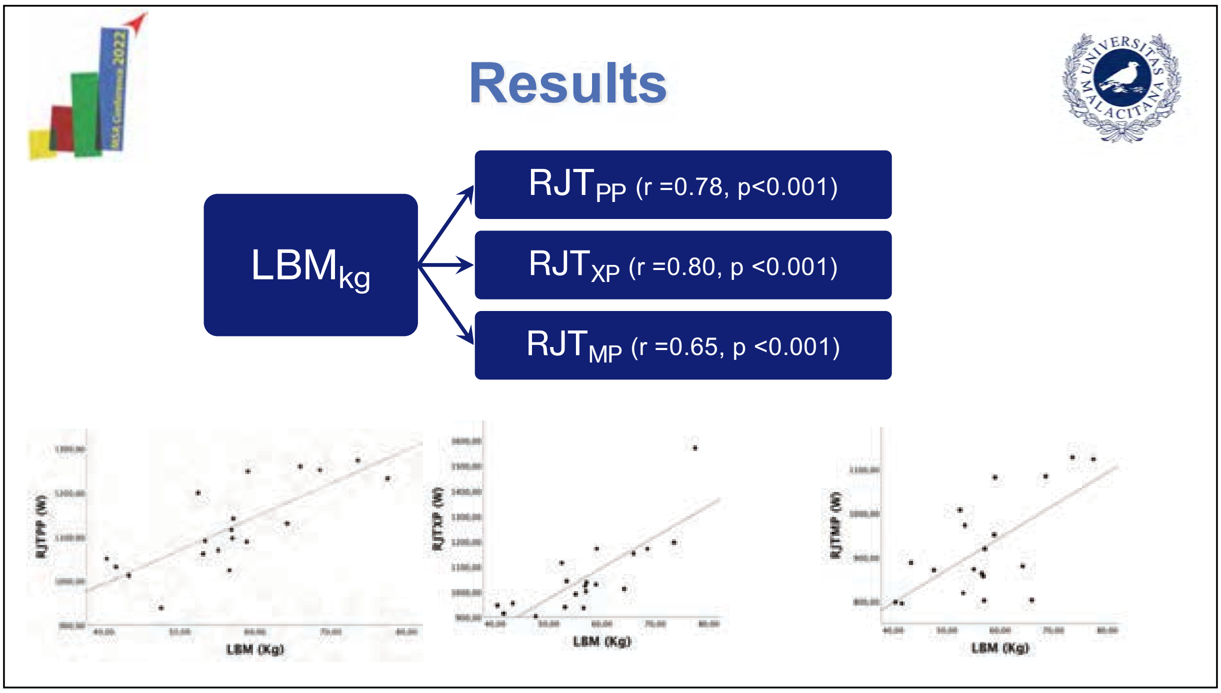
Statistics:

-Medcalc Software

-Pearson correlation coefficient

-Stepwise multiple regression

MedCalc
easy-to-use statistical software



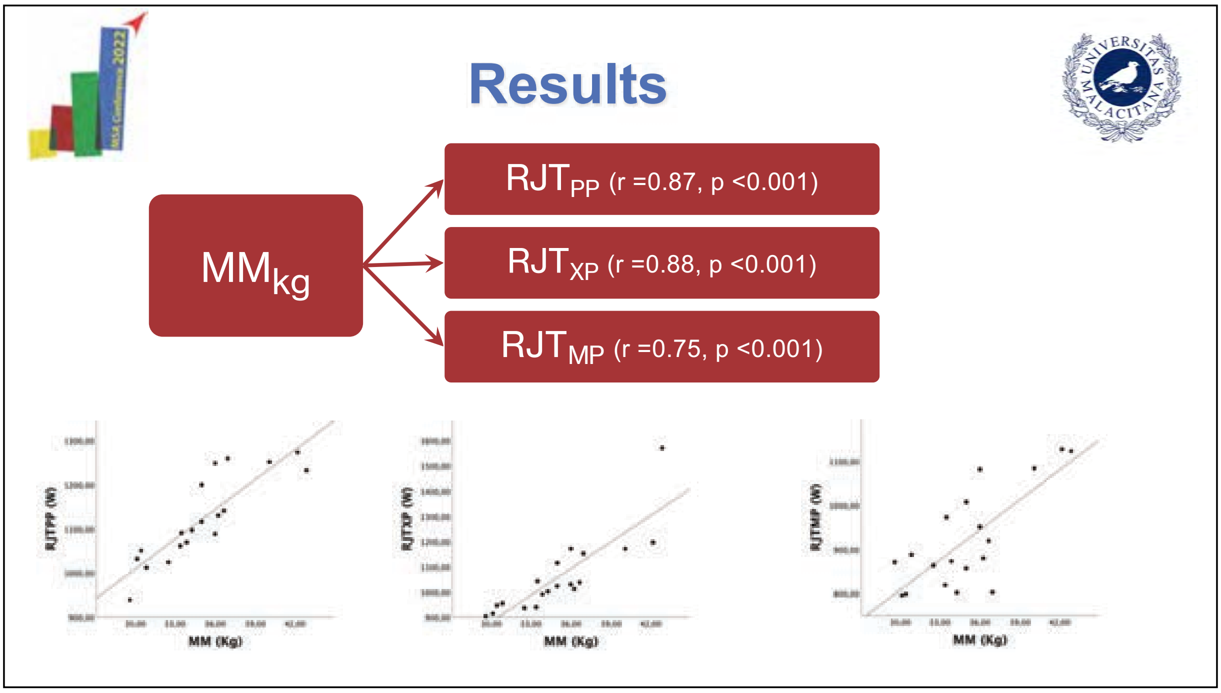
Results

LBM$_{kg}$

RJT$_{PP}$ (r =0.78, p<0.001)

RJT$_{XP}$ (r =0.80, p <0.001)

RJT$_{MP}$ (r =0.65, p <0.001)



Results

MM$_{kg}$

RJT$_{PP}$ (r =0.87, p <0.001)

RJT$_{XP}$ (r =0.88, p <0.001)

RJT$_{MP}$ (r =0.75, p <0.001)

Results

MM_{kg}

$RJT_{PP} = 330.438 + 22.602*MM_{kg}$

$R^2= 0.74$, SEE= 3.1678W, $p<0.001$

$RJT_{XP} = 237.1671 + 22.830*MM_{kg}$

$R^2= 0.75$, SEE= 3.0434W, $p<0.001$

Discussion

-Pearson et al., 2019 → LBM ↔ Anaerobic perf, → Baseball players

-Maciejczyk et al., 2014 → LBM ↔ Anaerobic perf, → Active people

-Vardar et al., 2007 → LBM ↔ Anaerobic perf, → Elite wrestlers

Nothing found in LBM or MM and RJT

Discussion

Limitations:

-Depth and velocity of CM

-Kinematic

-Lower Body length

(Pérez-Castilla et al, 2021; Daugherty et al, 2021)

Conclusion

Moderate-high correlation between LBM and MM and all power values

MM_{kg} is a strong predictor of repeated jump performance in CF athletes, explaining over 70% of PP and XP

APPENDIX 7

Oral communication presented in November 2022
At the BASES Conference
British Association of Sport and Exercise Sciences
in Leicester. United Kingdom.

ASSOCIATION BETWEEN WHOLE BODY PHASE ANGLE AND ANAEROBIC PERFORMANCE IN CROSSFIT® ATHLETES.

Ponce-García, T., García-Romero, J., Castillo-Domínguez, A., Carrasco-Fernández , L., Pacheco-Pérez, L., Benítez-Porres, J.

The use of bioelectrical impedance analysis (BIA) has been extended for the analysis of body composition. Additionally, in recent years, one of the raw variables measured by this method, the Phase Angle (PA) at 50 Khz of both segmental and whole body, has gained special attention due to its ability to determine nutritional and functional status. It has been associated with muscle strength and aerobic fitness in people suffering from different conditions (Norman et al., 2012) and higher in athletes compared to controls and athletes with higher levels of performance (Di Vincenzo et al., 2019). However, to our knowledge, there is no study conducted to assess its relationship with the physical abilities of CrossFit® (CF) athletes. Therefore, the main purpose of this study was to correlate the phase angle, specifically the whole-body phase angle (WBPA), with the anaerobic performance in CF athletes. Fifty CF athletes (25 male and 25 female) were recruited to participate (age 33.3 ± 6.81 years; stature 169.61 ± 8.76 cm; weight 72.78 ± 12.18 kg). Participants were tested in two sessions within a week, one for bio-impedance and one for the all-out test. For the Bio-Impedance session, they were asked to come to the laboratory fasting or not having eaten or drunk anything for at least 4 hours. Whole-body Phase Angle was determined. To assess anaerobic performance, the Wingate test was performed. This test consists of 30 seconds at maximum effort on a cycle ergometer. Peak (WGPP), mean (WGXP) and minimum power (WGMP) were determined. For the all-out session, they were advised to refrain from high-intensity physical activity for 24 hours before testing. All procedures were approved by the ethics committee of the University of Malaga. WBPA showed significant correlation with WGPP ($r = 0.67, p < 0.01$), WGXP ($r = 0.69, p < 0.01$) and WG MP ($r = 0.52, p < 0.01$). In conclusion, our results show that WBPA is directly associated with power values which suggests that it might be considered as an indicator of anaerobic performance.

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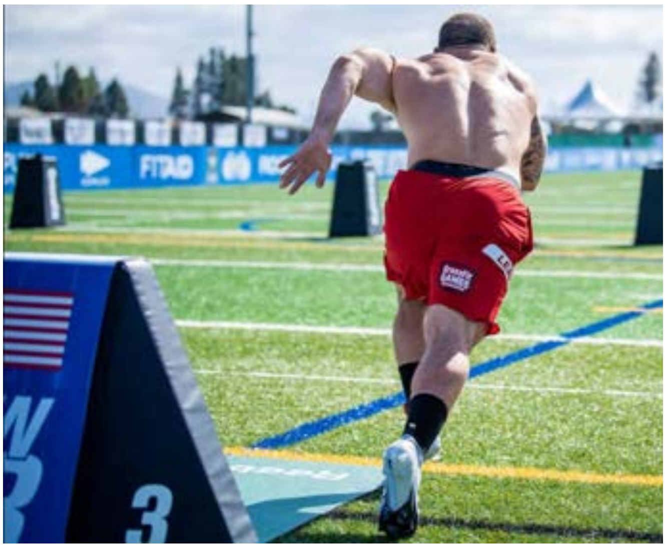
Association between whole body phase angle and anaerobic performance in CrossFit® athletes

Tomas Ponce-García, Jerónimo García-Romero, Alejandro Castillo-Domínguez, Laura Carrasco-Fernández, Luis Pacheco-Pérez, Javier Benítez-Porres

BASES 2022 Conference

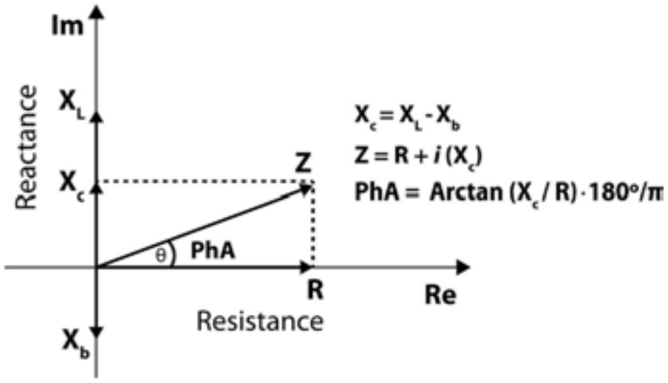
UNIVERSIDAD DE MÁLAGA

Introduction



Whole Body Phase Angle

"The geometrical angular transformation of the ratio between reactance (Xc) and resistance (R)" (Sardinha, 2018)



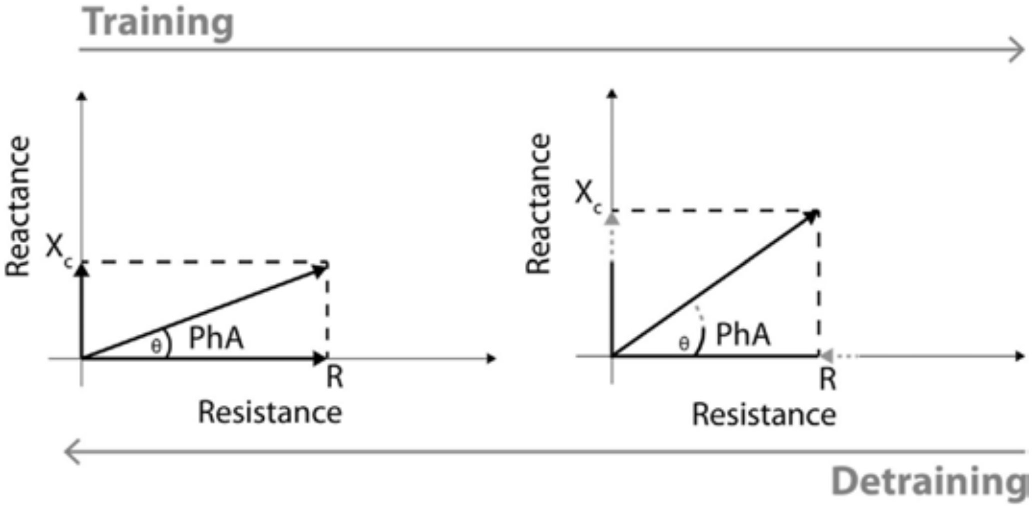
Whole Body Phase Angle

- Raw BIA variable

- Bioelectric characteristics of the cells

- 50 Khz

Whole Body Phase Angle



(Sardinha, 2018; Martins et al., 2022)

Whole Body Phase Angle

Other Populations:

- Nutritional and Functional status (Norman et al., 2012)

- Muscle strength and aerobic fitness in people suffering from different conditions (Norman et al., 2012)

- Correlated to the total muscle mass in older female adults (Silva et al., 2012)

Whole Body Phase Angle

Athletes:

- Upper body strength and lower body power in athletes (Hetherington-Rauth et al., 2021)

- Total and Regional BMD in female athletes (Martins et al., 2021)

- 10m and 30m sprint times and RSA (repeated sprint Ability) in young male soccer players (Martins et al., 2021)

- Lower limb muscle strength and jump performance in adolescent athletes (Knutsen et al., 2015)

Purpose

To correlate Whole Body Phase Angle with Anaerobic performance in CrossFit® athletes

Methods

Participants

-50 CF Athletes:
  - -25 male and 25 female
  - -Age: 33.3 ± 6.81 years
  - -Height: 169.61 ± 8.76 cm
  - -Body mass: 72.78 ± 12.18 kg

Inclusion criteria:
-One year experience
-3 hours per week
-No injuries or pathologies

Whole Body Phase Angle

Bio-Electrical Impedance (Inbody 770):

Whole Body Phase Angle (º)

-Fasting or **NO** drinks or food for 4h

-**NO** Alcohol for 24h

-**NO** diuretics for a week

Anaerobic Performance

Wingate Test (Monark 894E):

-All-out Test 30s

-Resistance:

- -7,5% bodymass – male
- -6% bodymass – female

Peak (WGPP), Mean (WGXP) and minimal (WGMP) power were determined.

Anaerobic Performance

Wingate Test:

5 min cycling (50-70 rpm)

5min Rest

TEST

Peak (WGPP), Mean (WGXP) and minimal (WGMP) power were determined.

Statistics

-Medcalc Software

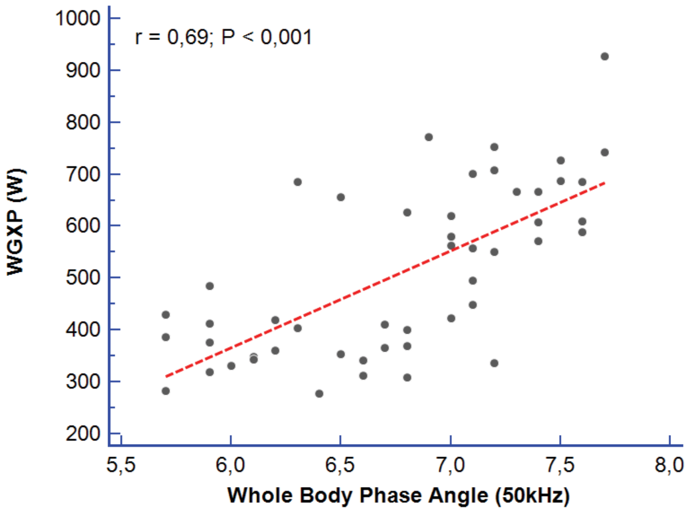
-Pearson correlation coefficient

MedCalc
easy-to-use statistical software

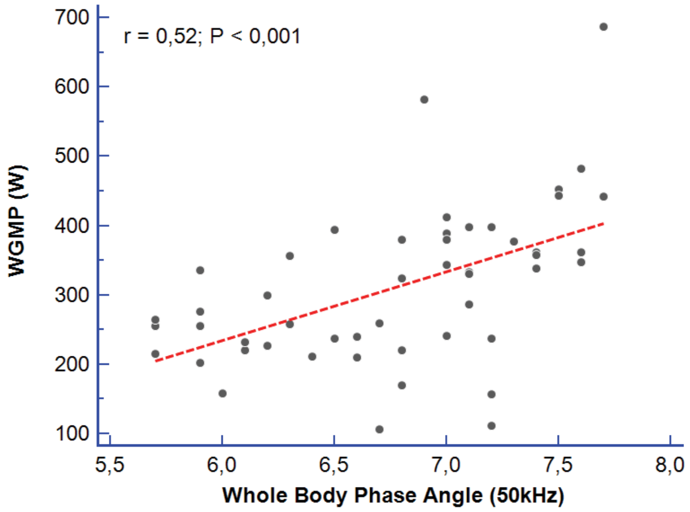
Results

Peak Power (WGPP)

Mean Power (WGXP)



Minimal Power (WGMP)



Discussion

Discussion

-Martins et al., 2021 → WBPA ↔ Sprint performance → Soccer players

-Hetherington-Rauth et al., 2021 → WBPA ↔ LB Power (CMJ) → Athletes

-Obayashi et al., 2021→ WBPA ↔ LB Strength & Power (SJ & CMJ) → Athletes

Nothing found in WBPA in CF Athletes

Limitations

-Training Load

-Experience (years of training)

-Any other variables: age, sex, etc…

Conclusion

Conclusion

Our results show that WBPA is directly associated with all power values which suggests that it might be considered as an indicator of anaerobic performance in CF athletes

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Practical implications

WBPA is a non-invasive health and functioning cell marker that can be used by coaches or sports professionals as a indicator of performance and muscle status along the season in CF athletes

APPENDIX 8

Poster communication presented in August-September 2022
At the 27th Annual Congress of the European College Of Sport Science
European College of Sport Science
in Seville, Spain

INTRACELLULAR BODY WATER AS A PREDICTOR OF ANAEROBIC PERFORMANCE IN CROSSFIT® ATHLETES.

Tomás Ponce-García, Jerónimo García-Romero, Laura Carrasco-Fernández, Javier Benítez-Porres

INTRODUCTION: Body composition and its relationship to physical performance in athletes from different sports has been broadly studied. Hydration status and body fluids distribution has gained interest for showing association with certain health and performance variables (Silva et al., 2014). The purpose of the present study was to correlate intracellular (ICW) and anaerobic performance in CrossFit® (CF) athletes and develop multiple regression models. **METHODS:** Thirty-four athletes (20 male; 14 female) volunteer to participate in this study (Age 32.55 ± 5.34 year; Height 171.29 ± 7.77 cm; Body Mass 73.88 ± 11.58 kg; BMI 25.13 ± 2.44). Intracellular (ICW) expressed in l were estimated by bioelectrical impedance analysis (Inbody 770, Cerritos, CA, USA). For the analysis, they were asked to come to the laboratory without having eaten or drunk anything for at least 4 hours. Anaerobic performance was tested by the Wingate test (WG), determining peak (WG_{PP}), mean (WG_{XP}) and minimal (WG_{MP}) power values. WG Test is an all-out test of 30s in a cycle ergometer. Pearson correlation coefficient was used to define the association between variables and stepwise multiple regression analysis to determine their relationship. **RESULTS:** ICW showed significant correlation with WG_{PP} ($r = 0.90$, $p < 0.001$), WG_{XP} ($r = 0.95$, $p < 0.001$) and WG_{MP} ($r = 0.65$, $p < 0.001$). Two equations models, explained by intracellular water, were developed for peak and mean power: $WG_{PP} = -341.0015 + 37.7110 * ICW$, R^2-ajusted= 0.80, SEE= 3.2942 W, $p < 0.001$: $WG_{XP} = -277.5285 + 28.3841 * ICW$, R^2-ajusted= 0.89, SEE= 1.7095 W, $p < 0.001$. **CONCLUSION:** Our results showed moderate to very-large correlation between ICW and anaerobic performance values. In summary, we can conclude that ICW is a strong predictor of anaerobic performance in CrossFit® athletes, explaining over 80% of power values.

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Intracellular Body Water as a predictor of anaerobic performance in CrossFit® Athletes

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Introduction

Body composition and its relationship to physical performance in athletes from different sports has been broadly studied. Furthermore, it has been widely used as a method of athlete selection, fitness monitoring and performance prediction along the season (Rudnev, 2020).

Hydration status and body fluids distribution has gained interest for showing association with certain health and performance variables (Silva, 2018)

Some authors have shown the relationship between intracelular body water (ICW) and maximal strength in Judo athletes (Silva et al., 2011) and, together with segmental lean soft tissue, to be a good predictor of jump performance in soccer players (Bongiovanni et al,, 2022)

However, no studies have been found correlating ICW and anaerobic performance, in CrossFit® (CF) athletes,

The purpose of the present study was to correlate intracelular water (ICW) and anaerobic performance in CF athletes and develop multiple regression models

Methods

Thirty-four athletes (20 male; 14 female) volunteer to participate in this study (Age 32.55 ± 5.34 year; Height 171.29 ± 7.77 cm; Body Mass 73.88 ± 11.58 kg; BMI 25.13 ± 2.44). They were tested in two separate sessions. Descriptive statistics are shown in Table 1,

Intracellular (ICW) expressed in L were estimated by bioelectrical impedance analysis (Inbody 770, Cerritos, CA, USA). Participants were asked to refrain from consuming any drink or food for at least 4 hours, alcohol in the last 48 hours, diuretics in the last 7 days, or having performed any strenuous physical activity in the previous 12 hours (Cruz et al., 2009).

Anaerobic performance was tested by the Wingate test (WG). The original versión, 30s all-out, was performed in a Monark cycle ergometer, model 894E (Monark Exercise AB, Vansbro, Sweden).

All participants provided a signed informed consent prior to participating in the study. All procedures were conducted according to the Declaration of Helsinki and were approved by the Ethics Committee of the University of Málaga.

Shapiro Wilk test for normality, Pearson correlation coefficient for the association and stepwise multiple regression analysis for the relationship of the variables were executed by the IBM® Corparation Statistical Package for the Social Sciences (SPSS®) software version 21 and the MedCalc Statistical Software (version 18.6) by MedCalc Software bvba.

$$WG_{PP} = -341.0015 + 37.7110 * ICW$$

$$WG_{XP} = -277.5285 + 28.3841 * ICW$$

Results

ICW showed significant correlation with WG_{PP} (r = 0.90, p < 0.001), WG_{XP} (r = 0.95, p < 0.001) and WG_{MP} (r = 0.65, p < 0.001). Two regression models, explained by intracellular water, were developed for peak and mean power: WG_{PP} = -341.0015 + 37.7110 * ICW, R2-ajusted= 0.80, SEE= 3.2942 W, p < 0.001: WG_{XP} = -277.5285 + 28.3841 * ICW, R2-ajusted= 0.89, SEE= 1.7095 W, p < 0.001.

One regression equation developed for peak power was developed and one for mean power, both explained by ICW. The results of the multiple regression analysis are shown in Table 2.

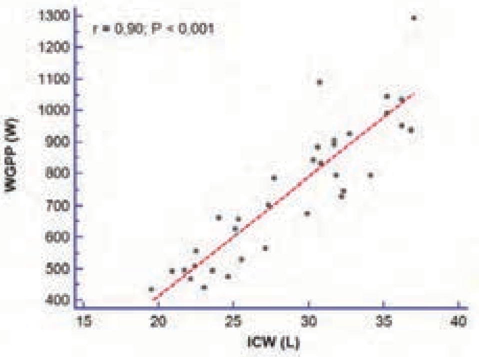
Table 1. Descriptive statistic

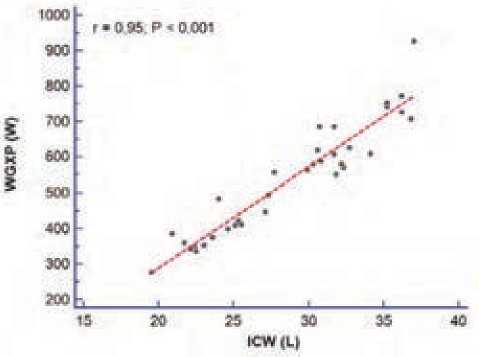
Variable	N	Mean	95% CI	SD	SEM	Normality
Age (years)	34	32.432	30.471-34.394	5.622	0.964	0.247
Height (cm)	34	171.291	168.581-174.001	7.767	1.332	0.037
BMI (kg/m^2)	34	25.126	24.274-25.979	2.444	0.419	0.479
ICW (L)	34	28.756	26.934-30.577	5.220	0.895	0.088
WG_{PP} (W)	34	743.414	666.798-820.031	219.585	37.659	0.155
WG_{XP} (W)	34	538.681	484.064-593.298	156.533	26.845	0.245
WG_{MP} (W)	34	321.004	277.821-364.187	123.764	21.225	0.187

BMI, Body Mass Index; ICW, Intracellular Water; WG_{PP} (W); peak power; WG_{XP} (W), mean power; WG_{MP} (W), minimal power; CI, confidence interval; SD, standard deviation; SEM, standard error of measurement; Normality, Shapiro Wilk Test.

Discussion & Conclusions

- Our results showed moderate to very-large correlation between ICW and anaerobic performance values.
- To our knowledge, there is no study conducted correlating ICW with anaerobic performance in CF athletes to compare our results. However, our results are in line with those of Bongiovani et al (2022) since they showed that the increase in ICW was related to improvement in jumping performance, an exercise that is also used to assess anaerobic power.
- As limitations, we can list the lack of records of some variables that could be related to the results, such as food intake, consumption of water and other beverages, as well as data on the menstrual cycle in girls.
- In summary, we can conclude that ICW is a strong predictor of anaerobic performance in CF athletes, explaining over 80% of power values.





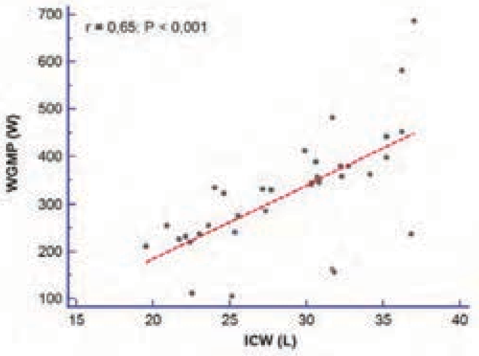


Table 2. Multiple regression models

Dependent variable	Independent variable	Coefficient	SE	P	VIF	R^2	R^2-ajusted
WG_{PP}	Constant	-341.0015				0.80	0.80
	ICW_L	37.7110	3.2942	<0.001	1		
WG_{XP}	Constant	-277.5285				0.90	0.89
	ICW_L	28.3841	1.7095	<0.001	1		
WG_{MP}	Constant	-124.7105				0.43	0.41
	ICW_L	15.4999	3.1715	<0.001	1		

WG_{PP}, peak power; WG_{XP}, mean power; WG_{MP}, minimal power; ICW_L, intracellular water; SE, standard error; VIF, variance inflation factor.

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APPENDIX 9

Poster Communication presented in October 2023
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La Red de Entrenamiento de Fuerza y Rendimiento Neuromuscular (REF)
in Madrid, Spain

RELACIÓN ENTRE EL ÍNDICE DE MASA LIBRE DE GRASA (FFMI) Y LA POTENCIA MÁXIMA Y MEDIA EN ATLETAS DE CROSSFIT®.

Tomas Ponce-García, Jerónimo García-Romero, Javier Benítez-Porres

INTRODUCCIÓN: el índice de masa libre de grasa (FFMI) es una medida ajustada a la altura de la masa libre de grasa (FFM) que se obtiene al dividir la FFM en kilos por la altura al cuadrado. La relación del FFMI y las características físicas y funcionales individuales ha sido ampliamente estudiada en diferentes poblaciones. En el ámbito deportivo, se han realizado estudios descriptivos relacionando los valores del FFMI con diferentes deportes o posiciones de juego (Trexler et al., 2017). Sin embargo, no hemos encontrado estudios en atletas de CrossFit® (CF). Por eso mismo, el objetivo de este trabajo es determinar la correlación entre el FFMI y la potencia y capacidad anaeróbica en estos deportistas. **MÉTODOS:** cincuenta atletas de CF participaron en este estudio (edad: 33.26 ± 6.81 años; masa corporal: 72.57 ± 12.17 kg; estatura: 169.55 ± 8.71 cm; BMI: 25.06 ± 2.31 $kg \cdot m^{-2}$; FFMI: 20.02 ± 2.52 $kg \cdot m^{-2}$) La masa libre de grasa (FFM) se midió mediante DXA. El FFMI fue determinado mediante la siguiente fórmula FFMI = FFM (kg)/estatura$(m)^2$.La potencia (WGPP) y capacidad anaeróbica (WGXP) fueron valorados mediante la prueba de máximo esfuerzo en cicloergómetro de laboratorio llamada Wingate (WG). Se utilizó el coeficiente de correlación de Pearson para definir la asociación entre las variables. **RESULTADOS:** el FFMI mostró correlación positiva significativa con WGPP ($r = 0.85$, $p < 0.001$) y la WGXP ($r = 0.90$, $p < 0.001$) en los atletas estudiados. Asimismo, se encontraron diferencias significativas en el FFMI y las variables de rendimiento anaeróbico entre hombres y mujeres ($p <0.001$). **DISCUSIÓN:** los resultados mostraron una correlación alta entre el FFMI y la potencia y capacidad anaeróbica. Por lo tanto, nuestros resultados sugieren que el FFMI debe ser tenido en cuenta como un determinante del rendimiento en este tipo de pruebas en atletas de CF.

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Relación entre el índice de masa libre de grasa (FFMI) y la potencia máxima y media en atletas de CrossFit®

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Introducción

El índice de masa libre de grasa (FFMI) es una medida ajustada a la altura de la masa libre de grasa (FFM) que se obtiene al dividir la masa libre de grasa total (WBLM) en kilos por la altura al cuadrado del participante. La relación del FFMI y las características físicas y funcionales individuales ha sido ampliamente estudiada en diferentes poblaciones.

En el ámbito deportivo, se han realizado estudios descriptivos relacionando los valores del FFMI con diferentes deportes o posiciones de juego (Currier et al., 2019; Trexler et al., 2017). Sin embargo, no hemos encontrado estudios realizados en atletas de CrossFit® (CF).

Por eso mismo, el objetivo de este trabajo es determinar la correlación entre el FFMI y la potencia y capacidad anaeróbica en estos deportistas.

Métodos

Cincuenta atletas de CF participaron en este estudio (edad: 33.26 ± 6.81 años; masa corporal: 72.57 ± 12.17 kg; estatura: 169.55 ± 8.71 cm; BMI: 25.06 ± 2.31 $kg \cdot m^{-2}$; FFMI: 20.02 ± 2.52 $kg \cdot m^{-2}$) La masa libre de grasa total (WBLM) se midió mediante DXA. Se pidió los participantes que acudieran al laboratorio en ayunas.

El FFMI fue determinado mediante la siguiente fórmula FFMI = WBLM(kg)/estatura$(m)^2$. La potencia (WGPP) y capacidad anaeróbica (WGXP) fueron valorados mediante la prueba de máximo esfuerzo en cicloergómetro de laboratorio llamada Wingate (WG). Se utilizó el coeficiente de correlación de Pearson para definir la asociación entre las variables. Los participantes proporcionaron un consentimiento informado firmado antes de participar en el estudio. Todos los procedimientos se realizaron según la Declaración de Helsinki y fueron aprobados por el Comité Ético de la Universidad de Málaga.

La prueba de normalidad de Shapiro Wilk, el coeficiente de correlación de Pearson para la asociación y el análisis de regresión múltiple por pasos para la relación de las variables se ejecutaron mediante el software IBM® Corparation Statistical Package for the Social Sciences (SPSS®) versión 21 y el software estadístico MedCalc (versión 18.6) de MedCalc Software bvba. Asimismo, se realizó la prueba *t* de student para la comparación de los grupos y se calculó el tamaño del efecto con la prueba *d* de Cohen. Se estableció el nivel de significación en <0.05.

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Resultados

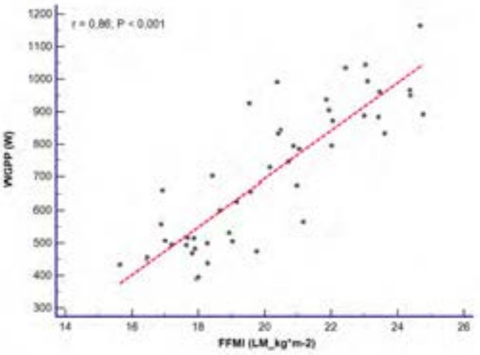
En la tabla 1 se muestran los estadísticos descriptivos de las variables, la comparación entre sexos y sus magnitudes del efecto. El FFMI mostró correlación positiva significativa con WGPP (r = 0.86, p < 0.001) y la WGXP (r = 0.91, p < 0.001) en los atletas estudiados.

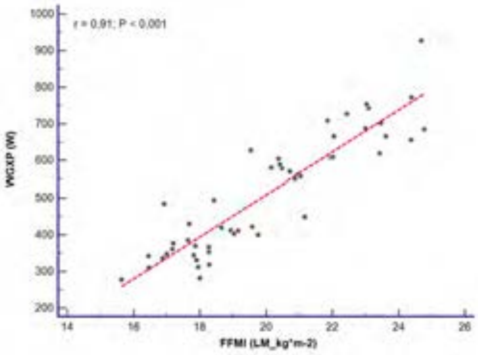
Asimismo, a excepción de la edad y la cantidad total de masa grasa (WBFM), se encontraron diferencias significativas en todas las variables estudiadas entre hombres y mujeres (p <0.001).

Tabla 1. Estadísticos descriptivos de las variables, comparación entre sexos y tamaños del efecto.

	Grupo (n=50)			Hombres (n=25)			Mujeres (n=25)				
	Media	**SD**	**SEM**	**Media**	**SD**	**SEM**	**Media**	**SD**	**SEM**	**t**	***d***
Edad (años)	33.26	6.81	0.96	33.32	5.84	1.17	33.20	7.78	1.56	0.95	0.02
Masa corporal (kg)	72.57	12.17	1.72	82.76	7.47	1.49	62.37	5.50	1.10	0.00	3.11
Estatura (mt)	1.70	0.09	0.01	1.77	0.04	0.01	1.62	0.05	0.01	0.00	3.19
BMI (kg·m−2)	25.06	2.31	0.33	26.43	2.03	0.41	23.70	1.70	0.34	0.00	1.46
FFMI ($LMkg \cdot m^{-2}$)	20.02	2.52	0.36	22.04	1.72	0.34	17.99	1.21	0.24	0.00	2.73
WBLM (kg)	58.20	12.15	1.72	69.01	6.15	1.23	47.39	4.46	0.89	0.00	4.02
WBFM (kg)	15.49	3.14	0.44	15.15	3.25	0.65	15.82	3.05	0.61	0.46	0.21
WBFM (%)	21.45	4.95	0.70	17.95	3.09	0.62	24.96	3.86	0.77	0.00	2.01
WGPP (W)	700.93	224.08	31.69	895.41	135.75	27.15	506.45	72.75	14.55	0.00	3.57
WGXP (W)	511.58	160.89	22.75	653.11	91.80	18.36	370.06	51.92	10.38	0.00	3.80

SD: desviación estandar; SEM: error estandar de la media; t: p valor de la prueba T de student; d: tamaño del efecto; BMI: índice de masa corporal; FFMI: índice de masa libre de grasa; WBLM: masa libre de grasa total en kg; WBFM: masa grasa total en kg; WBFMP: porcentaje de masa grasa; WGPP: potencia máxima en vatios; WGXP: potencia media en vatios.





Discusión

Los resultados mostraron una correlación muy alta entre el FFMI y la potencia máxima y media.

No se han encontrado estudios en los que se analicen la relación de los valores de FFMI con el rendimiento en atletas de otros deportes ni acerca de las mismas variables estudiadas en atletas de CF por lo que no podemos comparar nuestros resultados con los de otros autores.

Por lo tanto, a partir de nuestros resultados podemos concluir que el FFMI debe ser tenido en cuenta como un determinante del rendimiento en este tipo de pruebas en atletas de CF.

APPENDIX 10

Table of supplementary data from Article 3

Table S1. Descriptive data of all absolute and relative performance values, gender comparison, effect sizes and percentage of differences

	Group (n=50)			Male (n=25)			Female (n=25)					
	Mean	SD	SEM	Mean	SD	SEM	Mean	SD	SEM	t	*d*	%-dif
WG.PP (W)	700.93	224.08	31.69	895.41	135.75	27.15	506.45	72.75	14.55	0.000	3.57	43.4
WG.rPP (W/kg)	9.32	1.68	0.24	10.57	1.16	0.23	8.07	1.09	0.22	0.000	2.22	23.6
WG.rPP.LM (W/kgLM)	11.82	1.71	0.24	12.96	1.43	0.29	10.69	1.10	0.22	0.000	1.78	17.5
WG.rPP.MM (W/kgMM)	20.09	2.80	0.40	21.79	2.59	0.52	18.39	1.82	0.36	0.000	1.52	15.6
WG.XP (W)	511.58	160.89	22.75	653.11	91.80	18.36	370.06	51.92	10.38	0.000	3.80	43.3
WG.rXP (W/kg)	6.79	1.13	0.16	7.70	0.63	0.13	5.89	0.71	0.14	0.000	2.71	23.6
WG.rXP.LM (W/kgLM)	8.62	1.08	0.15	9.44	0.75	0.15	7.79	0.64	0.13	0.000	2.36	17.5
WG.rXP.MM (W/kgMM)	14.66	1.81	0.26	15.88	1.41	0.28	13.43	1.28	0.26	0.000	1.81	15.4
WG.FI (%)	54.84	10.31	1.46	56.59	9.24	1.85	53.09	11.20	2.24	0.235	0.34	6.2
RJT.PP (W)	977.81	252.19	36.40	1182.21	178.32	36.40	773.42	104.77	21.39	0.000	2.80	34.6
RJT.rPP (W/kg)	13.35	1.82	0.26	14.25	1.73	0.35	12.44	1.42	0.29	0.000	1.14	12.7
RJT.rPP.LM (W/kgLM)	16.76	1.98	0.29	17.14	2.17	0.44	16.38	1.73	0.35	0.186	0.39	4.4
RJT.rPP.MM (W/kgMM)	28.49	3.14	0.45	28.76	3.62	0.74	28.23	2.62	0.53	0.566	0.17	1.8
RJT.XP (W)	651.94	233.22	33.66	839.14	150.70	30.76	464.74	123.70	25.25	0.000	2.72	44.6
RJT.rXP (W/kg)	8.80	2.16	0.31	10.11	1.49	0.30	7.49	1.95	0.40	0.000	1.51	25.9
RJT.rXP.LM (W/kgLM)	10.99	2.40	0.35	12.16	1.88	0.38	9.83	2.32	0.47	0.000	1.11	19.2
RJT.rXP.MM (W/kgMM)	18.64	3.79	0.55	20.40	3.14	0.64	16.88	3.61	0.74	0.001	1.04	17.3
RJT.FI (%)	59.16	14.33	2.07	53.48	13.04	2.66	64.84	13.49	2.75	0.005	0.86	-17.5
AST.PP (W)	1157.41	347.98	49.21	1418.99	295.31	59.06	895.83	132.18	26.44	0.000	2.29	36.9
AST.rPP (W/kg)	15.34	2.63	0.37	16.68	2.56	0.51	14.00	1.95	0.39	0.000	1.18	16.1
AST.rPP.LM (W/kgLM)	19.71	2.92	0.41	20.49	3.27	0.65	18.93	2.34	0.47	0.059	0.55	7.6
AST.rPP.MM (W/kgMM)	33.51	4.88	0.69	34.47	5.82	1.16	32.55	3.58	0.72	0.206	0.40	5.6
AST.XP (W)	1016.83	308.88	43.68	1254.09	241.85	48.37	779.57	137.91	27.58	0.000	2.41	37.8
AST.rXP (W/kg)	13.45	2.32	0.33	14.74	1.99	0.40	12.16	1.90	0.38	0.000	1.33	17.5
AST.rXP.LM (W/kgLM)	17.27	2.48	0.35	18.11	2.53	0.51	16.43	2.16	0.43	0.015	0.71	9.3
AST.rXP.MM (W/kgMM)	29.35	4.13	0.58	30.46	4.54	0.91	28.25	3.41	0.68	0.057	0.55	7.3
AST.FI (%)	28.17	10.26	1.45	25.51	9.62	1.92	30.82	10.37	2.07	0.067	0.53	-17.2

SD: standard deviation; SEM: standard error of the mean; t: significance of t-student analysis; d: Cohen d effect size; WG: Wingate test; RJT: repeated jump test; AST: anaerobic squat test; PP: peak power in watts; rPP: peak power relative to body mass in watts per kg (W/kg); rPP.LM: peak power relative to lean mass in watts per kg (W/kgLM); rPP.MM: peak power relative to muscle mass in watts per kg (W/kgMM); XP: mean power in watts; rXP: mean power relative to body mass in watts per kg (W/kg); rXP.LM: mean power relative to lean mass in watts per kg (W/kgLM); rXP.MM: mean power relative to muscle mass in watts per kg (W/kgMM); FI: fatigue index.

APPENDIX 11

Ethics Committee approval document

UNIVERSIDAD
DE MÁLAGA

ANDALUCÍA TECH
Campus de Excelencia Internacional

Vicerrectorado de Investigación y Transferencia
Comité Ético de Experimentación de la Universidad de Málaga
(CEUMA)

Nº: 526	Nº de Registro CEUMA: 43-2018-H

INFORME DEL COMITÉ ÉTICO DE EXPERIMENTACIÓN DE LA UNIVERSIDAD DE MÁLAGA

CEUMA

Reunido el Comité Ético de Experimentación en Málaga, entre el 28 de junio y el 12 de julio de 2019 ha evaluado la solicitud del proyecto denominado: "**Estudio para validar y comparar un test de rendimiento deportivo alternativo**", cuyo investigador principal es **D. Jerónimo Carmelo García Romero.**

Una vez examinada la documentación presentada y verificados aquellos aspectos relacionados con la ética y la legislación en materia de investigación que se indican:

-Se cumplen los requisitos necesarios de idoneidad del protocolo en relación con los objetivos del estudio y están justificados los riesgos y molestias previsibles para el sujeto, teniendo en cuenta los beneficios esperados.

- El procedimiento para obtener el consentimiento informado, incluyendo la hoja de información al sujeto son correctos.

- La idoneidad del procedimiento experimental, especialmente la posibilidad de alcanzar conclusiones válidas de acuerdo con los objetivos establecidos.

- La capacidad del investigador principal y sus colaboradores los medios y las instalaciones previstas son apropiados para llevar a cabo dicho estudio.

- El alcance de las compensaciones y motivaciones previstas no interfiere con el respeto a los postulados éticos.

Acuerda por consenso emitir Informe Ético FAVORABLE para dicho proyecto.

Nº: 526	Nº de Registro CEUMA: 43-2018-H

Para que así conste D. TEODOMIRO LÓPEZ NAVARRETE, Vicerrector de Investigación y Transferencia y Presidente del Comité Ético de Investigación de la Universidad de Málaga lo firma en Málaga a 15 de julio de 2019.

Fdo: Teodomiro López Navarrete.

Una vez instruido el procedimiento, y en base a lo dispuesto en el artículo 84 de la Ley 30/92, de 26 de noviembre, de Régimen Jurídico de las Administraciones Públicas y Procedimiento Administrativo Común, se le da audiencia para que en un plazo de 10 días, contados a partir de la recepción/publicación del presente informe, pueda formular alegaciones y presentar los documentos y justificaciones que estime pertinentes.

"Science serves to give us an idea of how vast our ignorance is."

Robert De Lamennais.

"Sapere aude."

Horacio.